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Past studies involving latencies of the eye and head have typically been confined to refixations along the horizontal periphery, with only limited data available involving the vertical periphery. Of the existing data involving the vertical periphery, most have been characterized by target displacements of less than 20 degrees with scarce head latency data. The present study was conducted as a logical follow-on to these studies by providing both eye and head latency data for refixations involving the horizontal and the vertical peripheries. Utilizing a helmet mounted oculometer and helmet sight system, response latencies, as well as patterns of eye and head movement, were investigated. The subjects performed a central ongoing manual tracking task while periodically receiving visual cues to classify letters on one of four peripheral monitors. Two monitors were positioned along the horizontal periphery and two along the vertical periphery. The results indicated no significant differences in the mean latency as a function of the target periphery. However,
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19. ABSTRACT (Continued):

the mean head latency was significantly longer for the lower vertical periphery. The
pattern of subjects' responses was typically characterized by "eye movement before
head movement," with some distinct strategics noted regarding the initiation
of head movement. Various interpretations are provided to address these
tendencies as well as the effect of the letter classification task on the eye
and head response.

Preface

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INTRODUCTION

A recent study by the National Academy of Sciences has noted that the number of cockpit controls per crew member has risen exponentially since the days of the SPAD biplane (McKean, 1982). Whereas, the Wright flyer was operated with only the crudest of instruments and controls, today's F-15 pilot must learn to master some 300 switches, dials, and knobs. While this provides the pilot with more information than ever before, at times it can tax the capabilities of the pilot to adequately perceive, process, and respond to the information. In response to a need to alleviate this information overload, the Armstrong Aerospace Medical Research Laboratory (AAMRL) is currently developing a new family of control/display devices collectively termed visually-coupled systems. Such systems would eliminate the need for a vast array of cockpit controls by providing, through the headgear, critical flight information, as well as 3-D visual and auditory representations of the pilot's surround. In addition, the pilot's eye and head position would be continuously monitored in order to facilitate eye and head mediated control of functions, such as aiming weapons and selecting switches in virtual space (Furness, 1986). As a result, various tasks requiring a manual response could be replaced by the natural movements of the eye and head.

There is evidence to suggest that the continuous monitoring of the pilot's eye movements may also provide insight to the pilot's information processing strategies. For instance, it has been proposed that an analysis of the manner in which the operator's eyes move and fixate may not only reflect the operator's attentional behavior (Hall & Cusack, 1972; Stern, 1980), but may also reflect the information input and, possibly, the workload experienced by the operator (Wierwille, 1979). Consequently, visually-coupled systems would not only provide a nonobtrusive means for examining such strategies, but may also serve as a device for identifying bottlenecks affecting pilot performance.

In an effort to more fully understand how eye and head mediated controls can best be implemented in the operational environment, AAMRL is conducting studies that investigate various characteristics of eye and head movement. One characteristic of current interest is the latency of the eye and head, since it provides a measure of the response time of the eye and head which may provide a useful metric in the further development of visually-coupled systems. The specific purpose of this investigation was to examine the nature of eye and head response characteristics following a visual cue to acquire peripheral targets. A dual-task paradigm was employed whereby a central tracking task was periodically interrupted by a visual cue to classify targets in the horizontal and vertical peripheries. Eye and head latency, along with recordings of eye and head response patterns, were collected, as well as

target classification response time and central task performance.

It should be mentioned that this effort was part of a larger investigation which also included several types of auditory cues. These auditory cues consisted of speech commands as well as tones representing the target locations. At times these auditory cues appeared to emanate from the target, while at other times they appeared to be centrally located. This report, however, will focus directly on the effect of the visual cue on the eye and head response without addressing the effects of the auditory cues. As the presentation of each cue type was blocked, the auditory cues should have no impact on the data reported herein.

Prior to the conduct of this investigation, an extensive review of the literature was undertaken in an effort to disclose the relevant physiological as well as psychological factors which affect the eye and head response. What follows is a synopsis of this review.

Eye Movement Systems

There are essentially five major control systems which govern eye movements. One type involves the slow tracking conjugate or pursuit eye movements used to track slowly-moving visual targets in the range of 1 to 30 deg/sec (Hall and Cusack, 1972; Young and Sheena, 1975). Pursuit movements are smoothly graded, while appearing to partially stabilize the image of the moving target or background on the retina, independent of the voluntary saccadic eye movement system (Young and Sheena, 1975). These movements are not generally under voluntary control but, rather, usually require the presence of a moving visual field for their execution (Robinson, 1965; Westheimer, 1954, both cited in Young and Sheena, 1975). An example of the pursuit control system is the eye movements executed while following birds flying across the sky.

A second type of control system consists of the slow vergence eye movements utilized in tracking between distant objects and close ones (Bahill and Stark, 1979). The vergence movements are considerably slower and smoother than the saccadic and pursuit eye movements, appear to be nonpredictive, and can reach maximum velocities on the order of 10 deg/sec over a range of nearly 15 degrees (Young and Sheena, 1975). An example of vergence eye movements is that of automobile drivers shifting fixation from the inside to the outside of the automobile.

A third type of control system consists of the compensatory eye movements characterized by smooth movements of the eyes which move equal and opposite to head movements in order to maintain stationary fixation during head movement (Robinson, 1979). Compensatory eye movements tend to stabilize the retinal image of fixed objects during head motion and are attributable both to semicircular canal stimulation sensing head motion, and to neck proprioception associated with the turning of the head on the trunk (Young and Sheena, 1975). An example of the compensatory control system is the ability to maintain a clear image on a stable object, even though head position may be simultaneously shifting from side to side.

A fourth type of control system is the nystagmus movements of the eyes. These movements tend to be oscillatory or unstable in nature and can be elicited in three ways: stimuli

in the visual field which move continuously past the observer, angular acceleration, or disorders of the oculomotor, vestibular, or central nervous systems (Hall and Cusack, 1972). Nystagmus can best be described through example. As mentioned previously, the compensatory eye movements serve to stabilize images on the retina during periods of head rotation (i.e., match eye velocity with that of the head). However, under periods of rapid head rotation, these compensatory movements (moving opposite to that of the rotation) become interrupted by fast flicks of the eyes moving in the direction of the rotation. These interruptions represent an effort by the eye to continue its task of matching eye and head velocity even though the eye has reset its position in relation to the outside world (Carpenter, 1977). These patterns of slow phase compensatory movements and quick phase anticompensatory movements are what are referred to as nystagmus. The direction of the nystagmus is identified by the movement of the fast phase, that is, the direction of the rotation, and it appears that the nystagmus stops if the rotation is maintained for about 20 to 30 seconds (Davson, 1976).

A fifth type of control system, and the most common, is the saccade. Since the saccade represents the control system under investigation in this study, a more thorough and detailed discussion is provided below.

The Nature of Saccades

The saccadic control system consists of the rapid movements of the eyes used to change fixation from one point to another (Young and Sheena, 1975). Although these movements are considered to be under voluntary control, they are also preprogrammed dynamic responses over which no effective control can be exerted once movement is initiated (Hall and Cusack, 1972; Robinson, 1979). That is, the saccade is regarded as a ballistic eye movement whose trajectory, once begun, cannot be influenced (Becker and Fuchs, 1969). Voluntary effort or practice, for example, will not alter saccadic velocity. Further support for the preprogrammed nature of saccades is provided by the observation that saccadic eye movements hit their targets very precisely, implying that initial programming before the movement begins is probable.

The purpose of saccades is to fixate a target image on the fovea, or high acuity region of the retina, corresponding to .6 to 1 degree of visual angle (Young and Sheena, 1975). Saccades appear to be generated by a two-part signal known as a pulse-step control signal (Bahill and Stark, 1979). Eyeball rotation is effected through the innervation of at least two muscles: an agonist, which shortens and pulls against the eyeball, and an antagonist, which lengthens and relaxes. The driving force for the eye movement is the pulse: a short burst of high frequency motoneuron firing for the agonist and a corresponding pause in motoneuron activity for the antagonist. The pulse serves to move the eyes rapidly from one point to another, while the step signal that follows serves to hold the eye in its new position. A pulse signal moves the eye much faster than a simple step signal: for example, a 10 degree vergence eye movement lasts approximately 500 milliseconds (ms), or about ten times longer than a saccade of the same magnitude.

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With reference to the observable, or more measurable performance characteristics of saccades, it appears that they reflect the behavior of a goal-seeking system or negative feedback system (Hendrickson, 1985). Hendrickson suggests that, since saccades redirect the eyes in such a manner that object images are projected on the fovea, it follows that the input into the saccadic-generating circuit (located in the superior colliculus), is a reference signal specifying a "desired" foveal image. The direction and amount of action that is required to "actualize" the desired foveal image, then, depends on the direction and amount of discrepancy between the reference signal and visual and proprioceptive feedback. The cerebellum then calibrates the motor response for gaze by dampening and correcting overshoot and oscillation.

Overshoot is a common characteristic among saccades of the human eye. Three distinct types have been identified, each distinguished by the way in which the eyes move back to their final position: (a) In dynamic overshoot there is a fast return phase (e.g., in a saccade with 1 degree of dynamic overshoot the return usually takes about 20 ms); (b) In glissadic overshoot there is a slow, gliding return, lasting for more than 200 ms; and (c) In static overshoot the eye remains fixed in the off-target position for between 150 and 200 ms, until visual feedback elicits a corrective saccade (Bahill and Stark, 1979).

As mentioned previously, saccades are generally considered voluntary, however, the selection of a saccade appears to consist only of a choice in the amplitude and direction, but not of its velocity (Robinson, 1979). Saccades are characterized by very high initial acceleration and final deceleration (up to 40,000 deg/sec^2) with peak velocities during the motion which vary with the amplitude of the saccade reaching, perhaps, as high as 400 to 600 deg/sec (Young and Sheena, 1975). However, the control mechanism appears to be non-linear, possessing a limited maximum velocity of approximately 550 deg/sec for saccades over about 20 degrees (Robinson, 1979). Therefore, a 20 degree saccade will take approximately 67 ms, and one of 40 degrees roughly 135 ms. As expected, the duration of saccades varies with the magnitude and can range from 30 to 120 ms (Mackensen, 1958, cited in Young and Sheena, 1975), with average standard deviations of 5 ms for magnitudes between 5 and 40 degrees (Robinson, 1964, cited in Becker and Fuchs, 1969). Consequently, the high velocity and corresponding short durations of saccades usually permit the eye to remain in a state of fixation approximately 95 percent of the total time (Yarbus, 1967).

The number of saccades necessary to acquire a target varies with target angle. For refixations up to about 20 degrees, one saccade will usually be executed; whereas between 20 and 40 degrees, either one or two saccades may occur. If two saccades do occur, they appear to be programmed in advance. When angles extend 40 degrees, two saccades are most commonly observed: a large initial saccade which travels about 90 percent of the distance, followed after a short latency, by a second smaller saccade which moves the eyes on target. For refixations over 40 degrees, one or two saccades are usually made to a maximum extent of about 45 degrees where further travel must await movement of the head (Robinson, 1979). It should be noted that variations in experimental variables can also affect the number of saccades. For instance, it has been shown that the number of saccades can increase from one to an average of more than three as the target angle increases from 40

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to 100 degrees along the horizontal periphery and the target is moderately dim (Robinson, Koth, and Ringenbach, 1976). Similarly, when more than 1 saccade is executed, there is a minimum delay or refractory period of 100 to 200 ms (Carpenter, 1977; Young and Sheena, 1975) regardless of whether or not the first and second saccades appear in the same periphery (Feinstein and Williams, 1972; cited in Carpenter, 1977). It is interesting to note that, during the actual movement of the saccade, little if any visual processing actually occurs, although the mechanism for this suppression is not yet clear (Robinson, 1979). Since saccades can be elicited by target jumps, they have served as the primary eye movement system investigated in the literature (Bahill and Stark, 1979), and, as mentioned previously, they serve as the control system of interest in this study. Discussion will now focus on a brief description of the two most critical factors under investigation in this study: eye and head latency, and patterns of eye and head movement. This will be followed by a discussion of the factors which affect these responses.

Eye and Head Latency

The latency of the eye (or head) can be defined as the length of the delay between the change of position of an object and the start of corrective or compensatory saccadic eye (or head) movements to maintain fixation on the object (Boff and Lincoln, 1988). In other words, the latency of the eye or head can begin with the time a given command is issued to elicit a saccade, until the time when the eye or head begins the initial movement. It has been estimated that the minimum amount of time necessary to elicit a saccade following a visual cue is 150 ms: approximately 80 ms for visual information to reach the cortex, and approximately 70 ms for cortical stimulation to elicit a saccadic movement (Fuchs, 1976).

While many studies have been conducted to provide estimates of eye and head latency, no consensus exists on criteria to describe the beginning and end of eye movements. Therefore, the researcher is left with establishing a criterion (White, Eason, and Bartlett, 1962). This problem is further compounded since the criteria used to determine the start of an eye and head response are rarely reported in the literature. Thus, the experimenter is not only unable to adopt previous criteria, but little data are available to assist in the establishment process. As a result, slight variations in latency responses across studies can be expected due to distinct eye and head latency criteria. Such data, however, still provide a valuable source for establishing eye and head latency trends (White et al., 1962). (see Appendix A for a description of the criteria developed for this study).

Eye and Head Response Patterns

The current literature reveals that, during the process of shifting one's gaze from one location to another, any of three eye and head response movement patterns are possible. These response patterns are respectively known as the classical, predictive, and simultaneous.

Classical response pattern

In the classical or typical response pattern, the eye begins to move towards the target first, followed approximately 50 ms later by the head (Bizzi, 1974; Nelson, London, and Robinson, 1978; Robinson, 1979; Robinson, et al., 1976; Robinson and Rath, 1976; and Robinson and Subelman, 1975). (See Figure 1). Since the eyes move first, and with a higher velocity than the head, the eyes will reach and fixate the target while the head is still moving. Then for the duration of the head movement the eyes will perform a compensatory eye movement whereby the eyes will maintain fixation on the target by performing a rotational movement counter to the movement of the head, thereby allowing the fovea to remain constantly on the target just acquired (Bizzi, 1974). The total response pattern is completed once the eyes are oriented directly toward the target stimulus (Bartz, 1979): a process commonly referred to as static fixation, whereby movement of the eye and head cease at the target (Robinson and Rath, 1977, cited in Bartz, 1979). However, the cessation of eye movement may precede that of head movement by as much as 100 ms (Stern, Goldstein, and Dunham, 1988).

The classical pattern has always been the typical response exhibited in studies involving a single task (Robinson, Koth, and Ringenbach, 1975, cited in Robinson and Bond, 1975). In such studies, the subject's sole task is to respond to the presence of some target stimulus presented in the horizontal periphery. The nature of the response to the target stimulus has ranged from the identification of letters and numbers to the simple detection of lights.

Predictive response pattern

The second type of eye and head movement response is commonly referred to as the predictive (Bizzi, 1974; Calhoun, 1987) or the eye and head compensation pattern (Robinson, 1979; Nelson et al., 1978). To avoid confusion with compensatory eye movement, it is referred to in this study as the predictive pattern. In the predictive pattern, the head begins an initial movement toward the target stimulus while the eye remains fixated on the central task for a brief period of time before initiating a saccade towards the target (Nelson et al., 1978 - see Figure 1). It has been estimated that the eventual onset of the first saccade is delayed by 100 to 200 ms (Robinson, 1979). Robinson further postulates that the angle through which the predictive pattern occurs is usually less than 15 degrees, and often only 5 or 10 degrees.

One of the earliest observations of the predictive pattern was in experiments with monkeys, who, after memorizing a set of reward contingencies, emitted the predictive response in anticipation of a visual stimulus presentation (Bizzi, 1974). There has been support that the predictive pattern may represent an unconscious learned phenomenon. It has been found that some subjects display this pattern when responding to the right or left side, some to one side only, and some never display the response at all (Robinson, 1979). However, Robinson is unsure if this strategy can be trained. Yet, there is additional evidence from studies of highway driving that the predictive pattern may indeed be a learned skill (Mourant and Grimson, 1977).

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CLASSICAL PATTERN
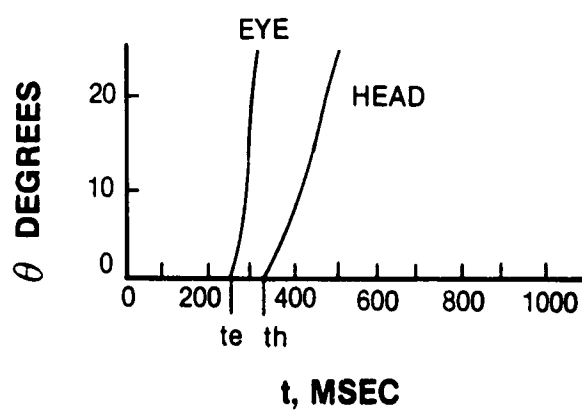
PREDICTIVE PATTERN

Figure 1. Eye and Head Movement Patterns

(From Robinson and Bond, 1975, p. 6).

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Simultaneous response pattern

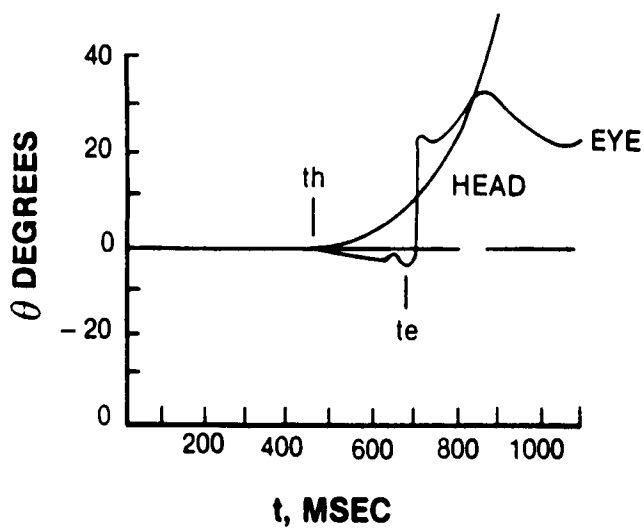The third type of eye and head movement response pattern involves a simultaneous movement of both the eye and head to the target stimulus (Sanders, 1970). Again, as the eye travels to the target stimulus with greater velocity than the head, it reaches the target first, where a compensatory eye movement is then initiated. To date, there has been very little research highlighting the distinct characteristics common to the simultaneous response pattern.

Factors Affecting the Eye and Head Response

The earliest scientific study of eye latency was reported by Erdmann and Dodge in 1897 (Miles, 1936). Using very primitive photographic techniques to detect eye movements to peripheral stimuli, these investigators reported latencies of 180 and 230 ms (2 subjects). Since that time, many additional studies have yielded similar results (Carpenter, 1977: 200 ms; Fuchs, 1976: 200 to 250 ms; Heywood and Churcher, 1980: 250 ms; Hou and Fender, 1979: 200 ms; Miller, 1969: 270 ms; and Tole and Young, 1981: 120 to 300 ms). Each of these studies employed a single task paradigm (the subject's only task was to respond to the peripheral stimuli). A number of studies have also investigated the eye and head response using a dual task paradigm (the subject must also attend to a central task). The central task has typically involved a manual tracking task (Bahrick, Fitts, and Rankin, 1952; Bartz, 1962; Calhoun, 1987; Cox, 1971; Robinson and Bond, 1975; and Robinson and Rath, 1976) or a fixation task (Bartz, 1966; Miller, 1969; and Robinson et al., 1976); while the peripheral task has involved the identification of letters (Calhoun, 1987), numbers (Bartz, 1962; Bartz, 1966; Robinson and Bond, 1975; and Robinson et al., 1976), lights (Bahrick et al., 1952; and Miller, 1969), simple arithmetic operations (Robinson and Rath, 1976), and the reading of instrument dials (Cox, 1971).

These dual task studies have investigated a wide variety of experimental variables. Independent variables of particular interest to this study have included: the presence versus the absence of a central control task, prior knowledge of target location, target angle, and target location. The dependent variables have included the eye and head latency, the eye and head response pattern, and the central task performance. It should be noted that, in some of these previous investigations, the central and peripheral tasks have competed for attention.

Prior to recent work, it was generally agreed that reaction time for the eye in acquiring a visual stimulus ranged from 150 to 200 ms and was only minimally affected by most task variables (Robinson, 1979). However, recent work with more precise eye movement recording techniques and devices allowing head movement have shown that a variety of factors can influence the response of the eye and head to refixations in the periphery. A formal discussion of these experimental factors and their effect on the eye and head response follows.

Presence of central control task

There is evidence to suggest that the presence of a competing, central, ongoing control task can produce both quantitatively and qualitatively different responses of eye and head movements (Robinson, 1979; Robinson and Bond, 1975). A quantitative difference is an increase in the eye latency time. Average increases in eye latency of 428 ms have been observed compared to 204 ms for the same subjects without the central control task (Robinson and Rath, 1976). In fact, the eye latency can be up to 700 ms if the interrupted central control task is felt to be more important than the peripheral display (Robinson, 1979). In addition, there is evidence to suggest that the presence of a central, ongoing task can affect one's ability to detect the peripheral stimuli (Leibowitz, 1973).

Qualitative differences which result from the presence of a central control task involve shifts from well ordered, highly correlated "head after eye" classical responses to "eye after head" predictive responses (Robinson and Bond, 1975). In studies having no central, ongoing task, the classical response has always been observed (Robinson, Koth, and Ringenbach, 1975, cited in Robinson and Bond, 1975); whereas, in studies conducted in the presence of a central, ongoing control task, the predictive response has been observed as well (Robinson, 1979; Nelson et al., 1978; and Robinson and Subelman, 1975). Leibowitz (1973) notes that when both foveally and peripherally presented stimuli compete for attention, the peripheral stimuli are treated with lower priority. As a result, the presence of the predictive response would appear practical, for such a response would allow the slower head to begin initial movement to the lower priority peripheral display, thereby allowing the eyes to maintain fixation on the higher priority central display until a decision is made to leave it. However, it can be argued that, under conditions where the peripheral stimuli are presented for only a matter of seconds, it is the peripheral stimuli which may receive the higher priority, for failure to immediately respond to the peripheral stimuli could result in a loss of information. Consequently, under such conditions the classical response would appear most appropriate.

Prior knowledge of target location

In general, the existing data tend to suggest that prior knowledge of target location can significantly decrease the eye and head latency (Robinson et al., 1976; Robinson and Rath, 1976). Prior uncertainty to target location has been found to increase eye latency time from 350 ms when prior knowledge is known, to 500 ms when no such information is given (Robinson, 1979). Robinson adds that prior uncertainty to target location can lead to a less-than-adequate first saccade, necessitating additional saccades and head movements in order to acquire the peripheral stimulus. In regard to head latency, prior uncertainty of target location can increase head latency by approximately 40 (Hackman, 1940; Robinson et al., 1976) to 60 ms (Robinson and Rath, 1976).

Target angle

Past research suggests that the number and duration of saccades and the number of head movements increase as the target moves towards the periphery (Becker and Fuchs, 1969;

Robinson, 1979; and Robinson and Rath, 1976). As mentioned previously, the number of saccades has been found to increase from one to an average of three as the target angle increases from 40 to 100 degrees along the horizontal periphery with a moderately dim target (Robinson et al., 1976). Similarly, it has been observed that, although head movements may occur with targets at 20 degrees, they will not be frequent until about 30 to 40 degrees displacement, with almost 100 percent movement for refixations over 45 degrees (Robinson, 1979). Sanders (1970) has identified three functional visual fields in the horizontal periphery based on target angle. These visual fields correspond to the degree to which eye and head movements are necessary in acquiring the target. These visual fields have been identified as: the *stationary field*, where peripheral viewing is sufficient; the *eye field*, where the supplemental use of eye movements is required; and the *head field*, where head movements as well as eye movements are needed in order to acquire the target. Sanders has observed that the size of the eye field varies with the operator's task, but the transition from eye field to head field is between 37 to 52 degrees off center.

There is some debate over whether or not eye latency is affected by target angle. While data exist showing increases in eye latency from 434 to 569 ms for target angles of 30 and 90 degrees, respectively (Robinson and Bond, 1975), and differences of 134 ms between 20 and 40 degree targets (Bartz, 1962); there are also data from a similar research paradigm showing no significant difference in eye latency among target angles (Robinson et al., 1976). Head latency, on the other hand, does not appear to be affected by target angle (Robinson and Rath, 1976; Robinson et al., 1976).

Target location

Only very limited data are available on performance changes in eye and head latency as a function of movement direction. The vast majority of the research has been performed in or very near the horizontal periphery (Berthoz, 1985; Hou and Fender, 1979; Robinson, 1979; Stern et al., 1988). Furthermore, of the available data, results are inconclusive. For instance, while slightly longer eye latencies have been observed for refixations along the vertical versus the horizontal periphery (Miles, 1936), others have observed no such differences in eye or head responses for any angle ranging from the horizontal to the vertical (Miller, 1969; Robinson, 1979 - eye responses; Jagacinski and Monk, 1985 - head responses).

However, consistent trends have been observed for comparisons conducted within each periphery, which suggest that target location may indeed affect the eye latency. For instance, eye latencies to upper target locations have been found to be shorter than eye latencies to lower target locations (Hackman, 1940; Heywood and Churcher, 1980). Yet, both of these studies failed to find any significant differences between left and right target locations. It has been suggested that such differences may be physiologically based, whereby movements in raising or lowering the line-of-sight may be accomplished more slowly than similar shifts to the right or left (Miles, 1936). It should be added that many of the studies that have addressed the effects of target location on eye latency have typically employed a single task paradigm with the head stabilized. Consequently, the angle of the target displacements have usually been limited to less than 20 degrees.

In addition, there are data to suggest that patterns of eye and head movement may be affected by target location. For instance, in a dual task study involving refixations in the lower vertical periphery, the classical response pattern was found in 83 percent of the responses (Calhoun, 1987). In comparison, in an automobile mirror sampling study (i.e., horizontal refixations), subjects elicited the predictive response in 63 percent of the responses (Mourant and Grimson, 1977). Granted, it is possible that these differences may not be entirely due to the target locations themselves, but, rather, may reflect differences associated with laboratory versus field investigations, as well as latency criteria.

Stimulus characteristics

A number of studies have investigated the effects of various stimulus characteristics (e.g., size, brightness, shape) on the latency response. Larger stimuli (4mm), for example, have been found to elicit slightly shorter eye latencies than smaller stimuli (2 mm - Miles, 1936). However, such differences were small (8.5 to 15 ms). The effect of the luminance of the stimulus remains unclear. While slightly longer eye latencies have been found for brighter, more discriminable targets (Robinson et al., 1976), a similar effort failed to find such an effect (Robinson and Rath, 1976). The shape of the stimulus may also affect the eye latency, where shorter latencies have been found following the presentation of geometric shapes (such as a visual bar), than for symbolic forms (such as numerals - Nelson et al.,1978).

In summary, following a command to refixate in single task experiments, the minimum delay in eye reaction time is approximately 300 ms (Robinson, 1979). Deviations in the eye and head latency, as well as differences in response movement patterns, can result from the presence of a central control task, prior knowledge of target location, target angle, target location, and certain characteristics of the stimulus.

Purpose

The present study was conducted to address some of the current data voids and research limitations. As mentioned previously, the majority of the research has been confined to refixations on or very near the horizontal periphery, with only limited data available involving the vertical periphery. Furthermore, of the data available involving the vertical periphery, most have been characterized by very small target displacements (less than 20 degrees), and scarce head latency data.

The present experiment investigated the response latencies of the eye and head performing refixations to the horizontal and vertical peripheries. The primary objective of the study was to examine these responses as a function of the target location. However, as pilots often operate under various levels of cognitive load, it was also decided to assess the effect of a memory scanning task (i.e., a Sternberg task - Glass, Holyoak, and Santa,1979) on such responses. The subjects performed a central ongoing manual tracking task while periodically receiving visual cues to complete letter classifications on one of four peripheral monitors. A state-of-the-art helmet mounted oculometer and helmet sight system were then used to collect the eye and head response time data.

The goal of the present study was to provide additional information into many of the issues formulated from past research. For instance, previous data suggest that the addition of the central task will contribute to slightly longer eye latencies than would be expected under single task conditions (i.e., greater than 300 ms; Robinson and Rath,1976), with potential differences in the eye latency as a function of target direction (Miles,1936; Hackman,1940; Heywood and Churcher,1980). Similarly, the effect of target direction may also result in distinctive patterns of eye and head movement, with the predictive pattern dominant along the horizontal periphery (Mourant and Grimson,1977; Robinson,1979), and the classical pattern dominant along the vertical periphery (Calhoun,1987). However, as this study is one of the first to investigate larger target displacements involving both the horizontal and vertical peripheries, perhaps some other trend will be identified. Similarly, as the target locations between the two peripheries are offset by 20 degrees (i.e., 60 degree target displacements along the horizontal, and 40 degree target displacements along the vertical) additional data are provided to examine, and perhaps further clarify, the effect of target angle on the eye and head responses. In addition, the study examines the strategies of eye and head movement in responding to the various target locations. Perhaps Sanders' notion of a functional visual field has relevance for refixations involving the vertical periphery. Or, as 40 degree target displacements fall within the area between the eye and head field, individual strategies will be found among the subjects. Finally, the study investigates, on a general level, the extent to which the central task is degraded while responding to the peripheral task.

METHOD

Experimental Design

A 2 x 4 mixed design was employed utilizing target presentations as Sternberg probes. The between-subject factor was memory set size: one positive target ("Q") versus five positive targets ("A", "H", "Q", "U", and "Z"). The within-subject factor was location of the peripheral target from the central monitor: horizontally left and right, vertically up and down. Five subjects were randomly assigned to each memory set size, and the order of the target locations was randomized, with the constraint that each location was represented equally in each run of 16 trials. The dependent variables consisted of the latency of the eye and head following the command to classify the peripheral target; the eye and head response pattern following the command (i.e., classical pattern, predictive pattern, or simultaneous pattern); verbal response time in classifying the target; and the degree of degradation in the central tracking task root-mean squared (RMS) performance when shifting attention to the peripheral target.

Apparatus

The study was conducted in the Helmet Mounted Oculometer Facility (HMOF) at AAMRL, located at Wright-Patterson Air Force Base. The overall configuration of the facility is shown in Figure 2, and a brief overview of the major system components follows.

Eye movement recording system

The movement of the eye with respect to the head (i.e., relative eye angle) was measured with an infrared corneal reflection system (Honeywell Helmet Mounted Oculometer; Figure 3). The subject's eye was illuminated by a halogen lamp filtered to pass only near-infrared light. This light was collimated and reflected into the subject's right eye from a small circular patch on the parabolic helmet visor. Some light was reflected from the cornea (first Purkinje image), while another portion of the light entered the pupil, reflected off the retina, exited the pupil, and was then scanned by a miniature charge-coupled device (CCD) video camera. The video signals from the camera contained bright spots, a bright disk, and spurious background reflections. The bright spots resulted from tears and reflections of the

HELMET MOUNTED OCULOMETER FACILITY (HMOF)

EYE & HEAD MOVEMENT MONITORS

MAGNETIC HELMET SIGHT

CAMERA & IR ELECTRONICS

VOICE RECOGNIZER/ SYNTHESIZER

NETWORK SYSTEMS HYPERCHANNEL ADAPTER

DATA GENERAL ECLIPSE S/130

SANDERS GRAPHIC 8

MICROVAX II

COCKPIT SIMULATOR

EXPERIMENTAL AREA

AUDITORY LOCALIZATION FACILITY (ALF)
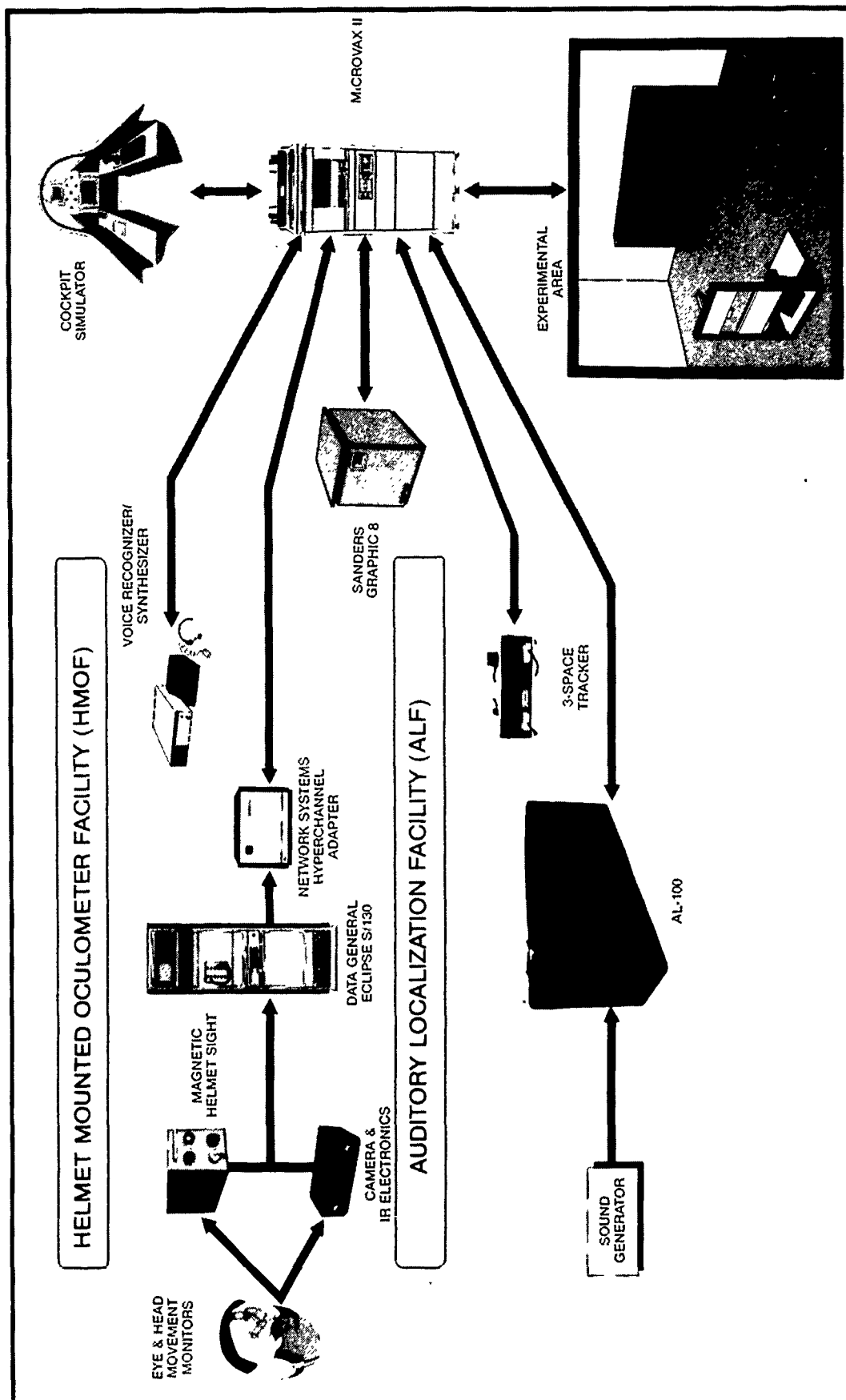
SOUND GENERATOR

AL-100

3-SPACE TRACKER

Figure 2. The Experimental Facility.

Figure 3. The Oculometer Device.

light source from the surface of the cornea, and the bright disk represented the reflected light energy from the retina after it had passed through the pupil.

As the cornea and the rest of the eye have a different radius of curvature, and as the eye rotates about its center of rotation to look around the visual field, the corneal reflection moves differentially with respect to the pupil (see Figure 4). Consequently, the azimuth and elevation angles of the eye, with respect to the helmet, were determined by the complex signal processing of a computer which sorted pupil and corneal reflections, determined relative positions of the center of the pupil and the center of the corneal reflection, rejected tearing, and accounted for the nonlinearity of raw subject data. At extreme angles of fixation (greater than 30 degrees), eye direction was determined by the shape of the pupil.

Head movement recording system

The weight of the helmet with its associated electronics, was 3 pounds, 13 ounces. In contrast to the standard Air Force helmet now in use, this provided an added weight of between 5 and 9 ounces. The increase in weight, however, was distributed evenly over the helmet. Extending from the lower rear of the helmet were the cables which transmitted the helmet position information to the Eclipse computer. A Honeywell magnetic Helmet Mounted Sight (HMS) provided accurate helmet position and attitude determination in six degrees-of-freedom with respect to a fixed coordinate system. The HMS utilized a transmitter mounted behind and above the helmet to create a magnetic field around the simulator and a helmet mounted receiver which responded to movement within this magnetic field by varying the output voltages. Based on these output voltages, helmet position and rotation were then computed with a Honeywell HDP- 5301 computer.

Supporting computer/software system

Eye angle data and helmet position and rotation data were combined by software in a Data General Eclipse S/130 computer to determine the eye line-of-sight with respect to a fixed coordinate system. All data were sampled at a rate of 60 Hertz (Hz). The total system RMS error was affected by many variables, including subject characteristics (e.g., pupil size and eye lash interference). At present, the RMS error is estimated to be 0.45 degrees or less at most eye positions (Calhoun, Arbak, and Boff, 1984).

The Eclipse computer was connected to a MicroVAX II computer via a special high speed Network Systems Hyperchannel A400 serial adapter. The MicroVAX matched the eye line-of-sight data from the Eclipse computer with eye calibration data to determine where the gaze was directed in the simulator. The MicroVAX also served as host for the experimental program by controlling the presentation of the tracking task, the visual cue, and the peripheral targets. The MicroVAX also collected and stored the eye and head position parameters, as well as the subjects' performance data. Various Statistical Analysis System (SAS) programs were then developed and a VAX 8650 computer was used for data analysis. In addition, a Nippon Electric Company Corporation DP-200 Speech Recognition and Synthesis system was used to record the subject's verbal responses.
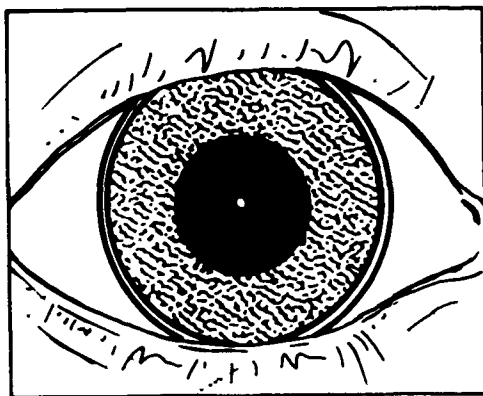
(a)
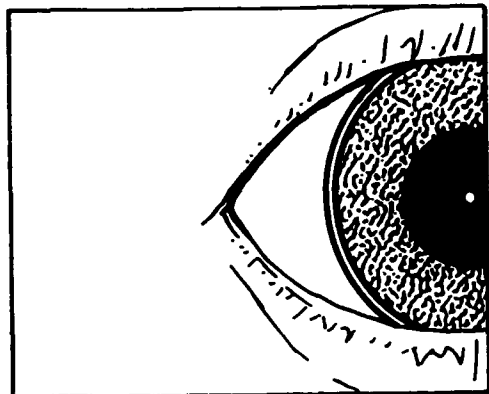
(b)
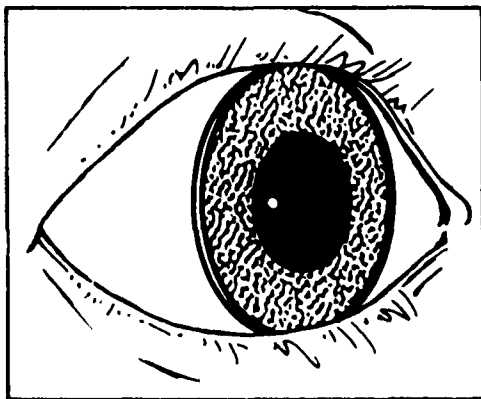
(c)
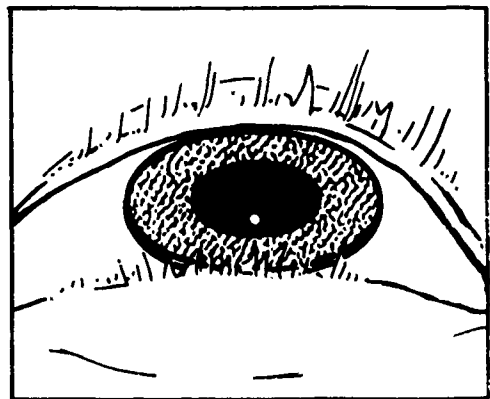
(d)

Figure 4. Illustration of the Differential Movement of the Corneal Reflection with respect to the Pupil during Eye Movements with a Stabilized Head: (a) eye looking straight ahead - corneal reflection at pupil center, (b) eye looking straight ahead but laterally displaced - corneal reflection still at pupil center, (c) eye looking to side - corneal reflection displaced horizontally from pupil center, (d) eye looking up - corneal reflection displaced vertically from pupil center. (From Young and Sheena, 1975, p. 414).

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Simulator

The central and peripheral tasks were presented on monitors mounted in and adjacent to a cockpit simulator (Figure 5). The central task was presented on a Hewlett-Packard X-Y monitor (approximately 12 x 10 cm - Model No. 1615 A), positioned at eye level, approximately 72 cm straight-ahead of the subject. The peripheral task was presented on four Panasonic monochrome monitors (approximately 19 x 14 cm - Model No. TR-930), located outside the viewing area for the central monitor. Specifically, two monitors were located in the horizontal periphery, such that the angular displacements of the targets were 60 degrees to the left and right of the center of the central monitor, while the other two monitors were located in the vertical periphery, such that the angular displacements of the targets were 40 degrees directly above and below the center of the central monitor. The 20 degree discrepancy between placements in the horizontal and vertical peripheries was due to physical constraints of the simulator. The peripheral targets were 4 mm in size and approximately 97 cm from the subject's nosebridge, subtending a constant visual angle of approximately .24 degrees. Similarly, the targets always appeared in the same central location on each monitor. An intercom system was connected to the helmet, enabling the subject to continuously communicate with the experimenter. The simulator was also equipped with a force stick located to the right of the seat which was used to perform the central tracking task. During testing, the cockpit area was darkened and a light-tight curtain surrounded the simulator. The average luminance of the targets and the symbology on the central monitor was .54 nits.

Eye calibration board

The eye calibration board was used to complete a linearization procedure. The board consisted of a large sheet of glass (approximately 8 feet high and 12 feet wide) with 51 red light-emitting diodes (LEDs) mounted on its surface. A description of the linearization procedure is forthcoming. In addition, a miniature version of the eye calibration board (containing seven fixation points) was installed in the simulator to facilitate a similar procedure prior to each experimental session.

Subjects

Ten members of a contractor-maintained pool served in this study. The subjects consisted of six females and four males ranging in age from 18 to 34 years with a mean of 23.3 years. These subjects were paid $ 5.00 per hour for their participation and were screened for any visual or aural anomalies. While soft contact lenses were permitted, only one subject used them. As handedness may be accompanied by different sensitivities to various portions of the visual field (Pirozzolo and Rayner, 1980), only right-handed subjects were used in this experiment.
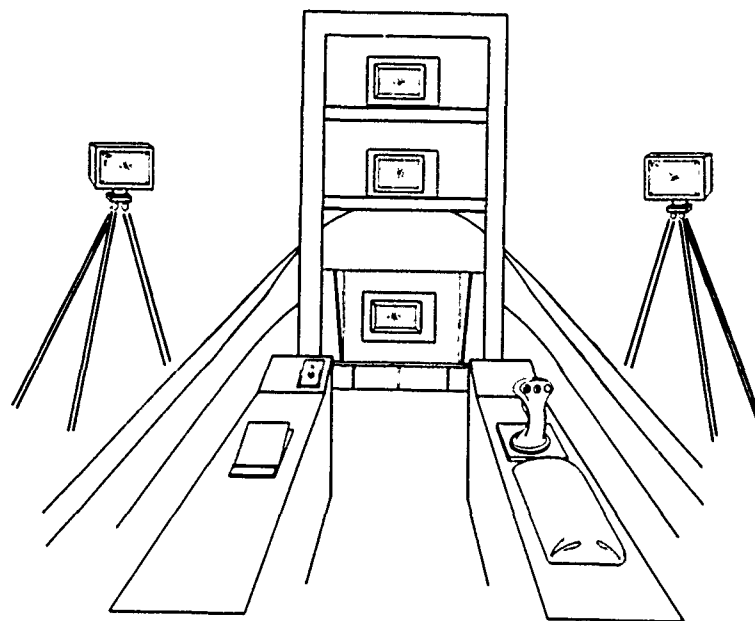
Figure 5. Schematic of the Simulator

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Subjects' Tasks

Each subject completed two concurrent tasks: a central task involving manual tracking, and a peripheral task involving Sternberg letter classifications presented on any of the four peripheral monitors. In an effort to control the allocation of attention between the two tasks, the subjects received a cash bonus (in addition to the hourly rate) whenever overall performance on *both* tasks improved from the previous day's level. Performance on the central task was judged by the overall RMS error, while performance on the peripheral task was judged by the verbal response time in classifying the target. The amount of the bonus was contingent upon the level of improvement from the previous session. If the improvement was greater than 1 standard deviation, then $1.75 was awarded for that task. If the improvement was within 1 standard deviation, then $.75 cents was awarded for that task. Each task was judged separately. Thus, a subject could earn a bonus of as much as $3.50 from one session. Any and all cash bonuses accrued during the experiment were awarded upon completion of the subjects' participation from the study.

Central task

Each subject completed a pursuit tracking task on the central monitor. The symbology was a dot representing command input, and a cross-hair representing system output. The subjects were instructed to place the dot over the continuously moving cross-hair by exerting pressure on the force stick. Tracking performance RMS error was then based on the difference (in inches) between the dot and the cross-hair.

Summed sine waves were used as the input forcing function in the horizontal and vertical axes. Past research (Junker and Levison, 1980) indicates that five summed sinusoids are sufficient to cause the subject to track the input as if it is a truly random process, rather than predicting the future of the input and tracking in a precognitive mode. Through the use of algorithms available in existing in-house programs, the sum-of-sine inputs were generated in terms of the number of component sinusoids and by the amplitude, frequency, and initial phase of each sinusoid. For the tracking level used in this study, the component sine waves were identical in frequency and amplitude. However, a number of forcing functions, differing in the phase relationships of the components, were generated and randomly assigned throughout the session.

Peripheral task

The peripheral task involved a Sternberg task whereby the subjects classified letters (targets) as members of a previously-memorized positive set. The positive targets consisted of the letters "A", "H", "Q", "U", and "Z", while the negative targets consisted of the remaining letters of the alphabet. The letters chosen to represent the positive set were selected at random from the entire alphabet. Each target presented was either a member of the positive or negative memory set.

For each trial a letter target was presented on *all* four peripheral monitors. It was deemed necessary to present a letter on each monitor, since the mere detection of a target

presentation on a single monitor would serve as an attentional cue in itself. Once the target was identified as positive or negative, the subject articulated one of two appropriate verbal responses. The verbal responses consisted of the words "Alpha" and "Bravo." These words were selected from a host of candidate terms (including those with positive and negative connotations) following a preliminary in-house pilot study which determined the response word pairs most readily identified by the voice recognition system used in this study. The assignment of the verbal responses was randomized with the constraint that each word was equally represented as the positive and negative response across subjects. Each verbal response issued by the subject was received by a helmet microphone which activated a timer to record the verbal response time, while the accuracy of the response was recorded manually and with the voice recognition system. The purpose of manually logging the subjects' responses was to assure accurate documentation. (see Appendixes B and C, respectively, for a description of the subject task instructions as well as the subject consent forms).

Procedure

The study was conducted in two phases: the first phase consisted of the pre-experimental procedures which prepared the subject for the study, while the second phase consisted of the actual procedures for data collection. A more thorough description of these procedures follows:

Phase 1 - Pre-experimental procedures

Upon arrival at the test facility the subject received a brief overview of the study and was given the consent form. Once consent was granted, the subject was prepared for linearization. Linearization was needed to correct for nonlinearities between the position of the corneal reflection center relative to the pupil center and eye directions. Such relationships are only approximately linear for angles up to 10 or 20 degrees, with significant nonlinearity at 30 degrees. These nonlinearities are due, in part, to the way in which the position of the center of the pupil is inferred from the partial boundary of an obliquely viewed, and thus elliptical, pupil, and in part, to the geometry of the eyeball (Merchant and Morrisette, 1973). These nonlinearities were corrected through the linearization procedure which mapped the unique qualities of the subject's eye to known line-of-sight angles. In this procedure, the subject's head was restrained while fixating on each of 51 light-emitting diode (LED) data points. The entire procedure was self-paced and lasted approximately one hour. The pupil video and corneal signals generated from this procedure were then correlated with the known spatial data points, and these data stored on disk where they were used by the computer to calculate eye angle data during the experiment.

Following linearization the subject recorded a voice recognition file. This procedure involved saying the words "Alpha" and "Bravo" repeatedly into the voice recognition system. Once recorded, the subject repeated the words with the voice recognition system to verify identification accuracy. Once the level of correct identifications was near 100 percent, the

voice recognition file was stored (otherwise the procedure was repeated), and the subject advanced to the final procedure of the session. The final procedure consisted of a practice run of the Sternberg task, conducted out of the simulator. The subject was provided with a description of the task, including the assigned memory set size and the verbal responses associated with classifying the positive and negative targets. The subject was then given approximately five minutes to rehearse the procedure. This was ample time to memorize the targets and the verbal responses. The experimenter then presented, on index cards, a single letter and asked the subject to respond with the appropriate verbal response. There were approximately 20 trials and the entire procedure (including the memorization) was conducted in less than ten minutes. At the conclusion of this procedure, the session was ended and the subject was scheduled for actual experimental data collection sessions.

Phase 2 - Experimental procedures

Upon arrival at the test facility, the subject was briefed on the experimental tasks, seated in the simulator, and then fitted with the helmet. Next, the subject performed an eye calibration and helmet boresight routine with the aid of a helmet restraint device and the miniature calibration board. The purpose of these preliminary routines was to "tune" the eye and head monitoring system to the particular characteristics of the subject's eye with respect to the helmet fit (which tends to vary from session to session). The eye calibration involved collecting data while the subject momentarily fixated on each of seven LEDs positioned across the front of the simulator, while the helmet boresight routine involved sampling the helmet position. These data, in combination with the linearization data, were then used by the computer to calculate the eye position during the experiment.

Once these procedures were completed, the subject was ready for data collection. Each run was initiated by having the subject perform the central tracking task. Following 5 seconds of this task, a visual bar was flashed on one of the four sides of the central task monitor screen. The visual bar was approximately 1 inch in length, and appeared for approximately 65 ms. The bar indicated the location of the monitor presenting the target for that particular trial. That is, if the bar flashed at the left edge of the screen, attention was to be directed to the left monitor for the target presentation. If the bar flashed at the top edge of the screen, attention was to be directed to the top monitor for the target presentation, and so forth for bar presentations to the right and bottom edges of the screen. Approximately 350 ms following the onset of the visual bar, a white letter was presented simultaneously on each of the four peripheral monitors (two positive targets and two negative targets). Consequently, the subject had to pay strict attention to the visual cue in order to respond to the appropriate monitor presenting the target. The target was presented 350 ms after the onset of the bar in order to minimize interference effects (i.e., delays) with the saccade latency, which are possible if both the bar and the target appear simultaneously (Ross and Ross, 1980). A delay of 350 ms (as opposed to a longer interval) further assured that the target was available before excursion to the target was completed. Upon presentation of the visual cue, the subject's task was to shift attention from the tracking task to the prescribed monitor, and classify the target (as positive or negative) by issuing the appropriate verbal

response into the helmet microphone. Once the response was made (or four seconds had elapsed), the target was extinguished, and the subject resumed the tracking task and awaited the next visual command.

The interval between commands ranged from 7 to 13 seconds (in order to inhibit anticipatory responses), and the subject received 16 commands or trials during each 5 minute run. The order of the target locations was randomized with the constraint that the subject received 4 commands to each location, and that, within these four occurrences, two positive and two negative targets randomly appeared. Each subject participated in three sessions, with each session consisting of 8 runs. Figures 6.A and 6.B depict the series of events which governed a typical trial and run, respectively.

Performance Measures

The dependent variables of interest in this study were:

1) eye latency — defined as the time from the visual command until the velocity of the eye was approximately 60 deg/sec between three consecutive data samples (50 ms). (See Appendix A for a description).

2) head latency — defined as the time from the visual command until the velocity of the head was approximately 15 deg/sec between three consecutive data samples. (See Appendix A for a description).

3) eye and head response pattern — the frequency of trials displaying the classical, predictive, and simultaneous patterns. The trials were classified by comparing the eye and head latency times for each trial. If the eye latency time was less than the head latency time, the pattern was identified as a classical response; if the eye latency time was greater than the head latency time, the pattern was identified as a predictive response; and if the eye and head latency times were equal, then the pattern was identified as a simultaneous response.

4) verbal response time — defined as the time from the visual command until the subject articulated the verbal response classifying the target. A voice activated switch was used for this purpose, and operated independently from the voice recognition system.

5) manual tracking performance — Performance on the central tracking task was represented by the difference in RMS error obtained between two segments of each trial: one, the RMS resulting from the segment of the trial where the sole event was the central tracking task; and two, the RMS resulting from the segment of the trial when the central tracking task was coupled with responding to the peripheral target. This difference between segments then provided a measure of the degradation to the central tracking task as a result of the peripheral task.

First Cue
Issued

Target
Presented

Subject Response Time
Target Extinguished

Next Cue
Issued

Initial Foreperiod		
5 seconds	350 ms	4 second maximum time	7-13 seconds

single task tracking dual task tracking single task tracking

? eye latency time

? head latency time

? verbal response time

Figure 6.a. Timeline for a Typical Trial.

Central Tracking
Task Begins

First Trial
Begins

5 seconds
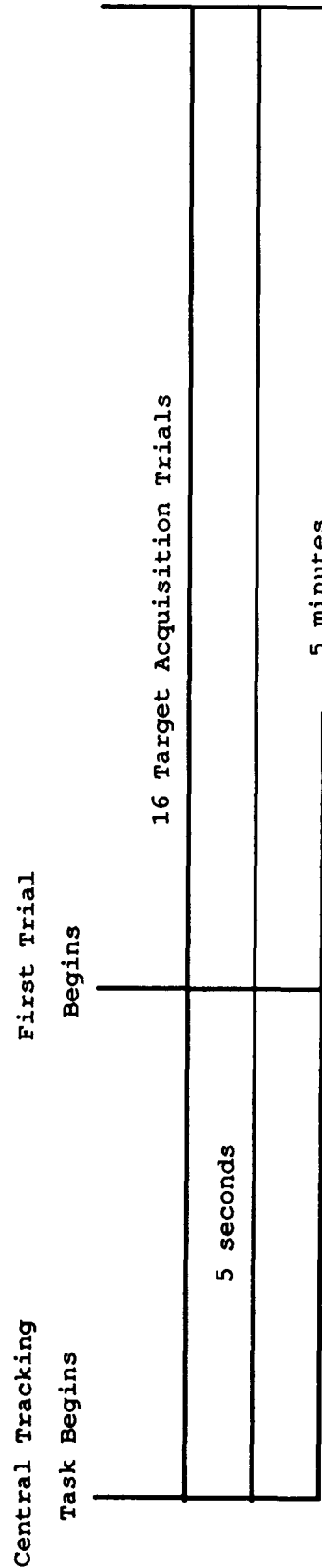
16 Target Acquisition Trials

5 minutes

Figure 6.b. Timeline for a Typical Run.

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RESULTS

Initial Data Preparation

Although each subject received 384 commands (trials) across the three sessions, only the responses from the final four runs (64 trials) were included in the data analyses. Thus, the subject's data represented well-practiced responses. These data were further screened to include only those trials where the subject's initial eye and head positions were directed towards the central monitor at the time of the command. Trials were also discarded when the eye and head latencies were less than 150 ms (may reflect anticipatory responses), or greater than four standard deviations from the grand mean (adopted from Heywood and Churcher, 1980). Trials were also deleted whenever the verbal response time or the RMS difference value surpassed four standard deviations from the respective grand mean. All errors in the verbal response were also identified and deleted from the data. On average, 6 trials were deleted per subject (approximately 9 %). An overall summary of the deleted trials is provided in Table 1. As a consequence of these various screening procedures, a grand total of 580 trials (approximately 91 % of the total data) were included in the data analyses, with the breakdown by target location as follows: 151 trials "LEFT", 137 trials "RIGHT", 146 trials "UP", and 146 trials "DOWN".

Prior to statistical analysis of these data, a Bartlett test of sphericity was performed using SPSSX to determine the appropriateness of univariate or multivariate analysis of variance procedures. A significant effect indicates that the correlations among the dependent variables are of sufficient magnitude to justify the multivariate analysis of variance (MANOVA); whereas, a non-significant effect indicates low correlations among the dependent variables and the appropriateness of univariate analysis of variance (ANOVA). As the actual test result was not significant (Bartlett $= 5.62$, $\underline{p} = 0.467$), separate ANOVA's were conducted on these data.

In addition, as reaction time data tend to be inherently skewed, the eye and head latency, as well as verbal response time data, were subjected to separate square root and natural log data transformations. However, as the resulting ANOVA's yielded the same effects as those for non-transformed data, the non-transformed data are reported herein. Table 2 presents the means and standard deviations for the eye and head latency as a function of memory set size and target location. It should be noted that the eye and head latency data included an undetermined system lag time. In an earlier, but similar, experiment, which used a PDP 11/34 system to control the test procedures, this lag time was found to be minimally 50

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Table 1

Trials Deleted from the Data Analyses

Condition	Trials
Violation of eye/head position at cuetime	3
Eye not tracked at cuetime	7
Outliers	
eye	23
head	11
verbal response	3
Verbal response errors	13
	60

Table 2

Eye and Head Latency Performance (ms)

Memory Set Size

Target	One Eye $\bar{x}$	σ	One Head $\bar{x}$	σ	Five Eye $\bar{x}$	σ	Five Head $\bar{x}$	σ	Overall Mean Eye	Overall Mean Head
Left	428	(54)	484	(32)	425	(56)	453	(65)	426	469
Right	399	(37)	467	(39)	414	(47)	458	(49)	406	463
Up	396	(45)	478	(70)	424	(44)	450	(67)	410	464
Down	426	(43)	508	(61)	408	(49)	519	(109)	417	514
Overall Mean	412		484		418		470		415	477

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ms.

Eye Latency

The mean overall eye latency was 415 ms, with average values ranging from 396 to 428 ms (Table 2). These latencies were slightly longer for the left and lower target locations (426 and 417 ms, respectively), while nearly identical for the right and upper target locations (406 and 410 ms, respectively ; see Figure 7). Likewise, the mean values were very similar between the two memory set sizes (412 and 418 ms for memory set size one and five, respectively). The results of the ANOVA, however, indicated no significant differences in the mean eye latency as a function of target location, memory set size, or the interaction of target location with memory set size (see Table 3). (It should be noted that a separate ANOVA was performed by target periphery which also failed to detect any significant effects).

Head Latency

The overall head latency was 477 ms, with average values ranging from 450 to 519 ms. The results of the ANOVA indicated a significant effect for target location (see Table 4). More specifically, the Tukey test (alpha = .05, critical range = 3.927) indicated that the head latencies were significantly longer for the lower target location (514 ms) than for either the left, right, or upper target location (469, 463, and 464 ms, respectively; see Figure 7). No significant effects were found for memory set size or for the interaction of target location with memory set size.

Eye and Head Response Patterns

Figures 8 and 9, respectively, present the percentages of each response pattern as a function of target location and memory set size. These percentages are based solely on those trials where both eye and head movement were initiated toward the target, for there were 49 trials (all along the vertical periphery) where no head movement was detected. One subject never initiated head movement when responding to the upper target location, while another subject exhibited the same tendency for the lower target location. Similarly, two other subjects displayed downward head movement less than 50% of the time.

An examination of Figures 8 and 9 shows that the classical "eye before head" response was by far the dominate response pattern, regardless of target location or memory set size. In fact, the classical response accounted for approximately 86 % of subject's responses across target location, whereas the predictive and simultaneous responses accounted for 8 and 6 %, respectively. The classical response was the only pattern which occurred at greater than chance proportions, $t = 14.25$, $p = .001$. However, the classical pattern did not differ significantly as a function of target location or memory set size (see Table 5). In the classical patterns detected, initiation of the eye typically preceded initiation of the
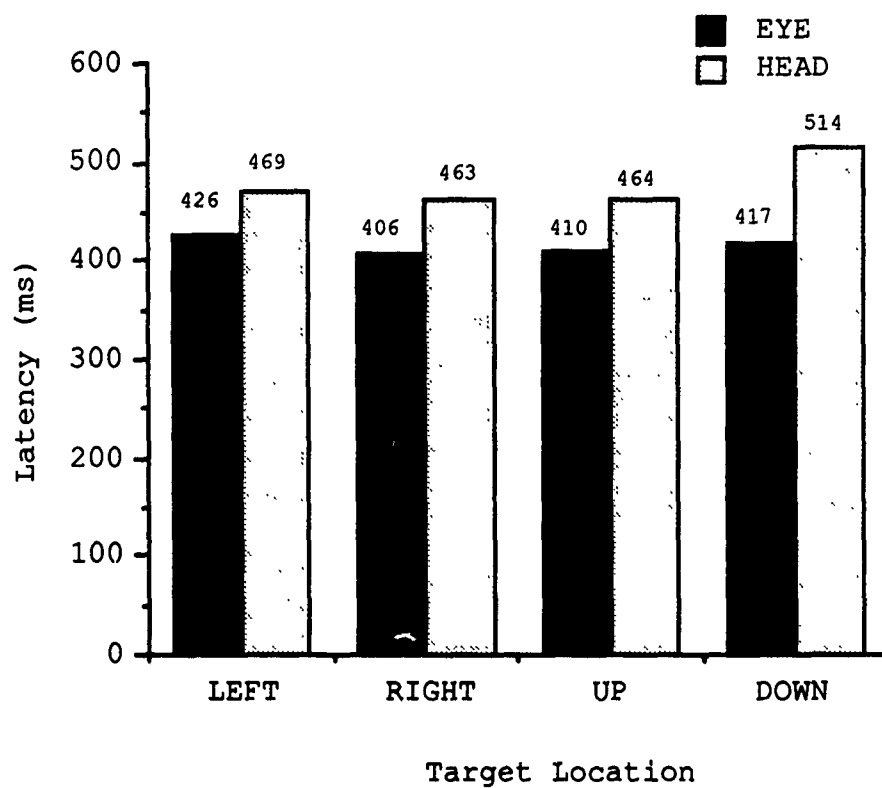
Figure 7. Latency as a Function of Target Location

Table 3

ANOVA for Mean Eye Latency

Source of Variance	SS	df	MS	Error Term	F	p
Memory Set Size (M)	0.0003	1	0.0003	Subject(M)	0.04	0.8375
Target Location (L)	0.0024	3	0.0008	L*Subject(M)	1.03	0.3986
M by L	0.0031	3	0.0010	L*Subject(M)	1.36	0.2797
Subject(M)	0.0534	8	0.0067			
L*Subject(M)	0.0184	24	0.0008			
Total	0.0776	39				

Table 4

ANOVA for Mean Head Latency

Source of Variance	SS	df	MS	Error Term	F	p
Memory Set Size (M)	0.0020	1	0.0020	Subject(M)	0.15	0.7086
Target Location (L)	0.0125	3	0.0042	L*Subject(M)	4.70	0.0111 *
M by L	0.0044	3	0.0015	L*Subject(M)	1.67	0.2022
Subject(M)	0.1088	8	0.0136			
L*Subject(M)	0.0195	22	0.0009			
Total	0.1472	37				

* Significant
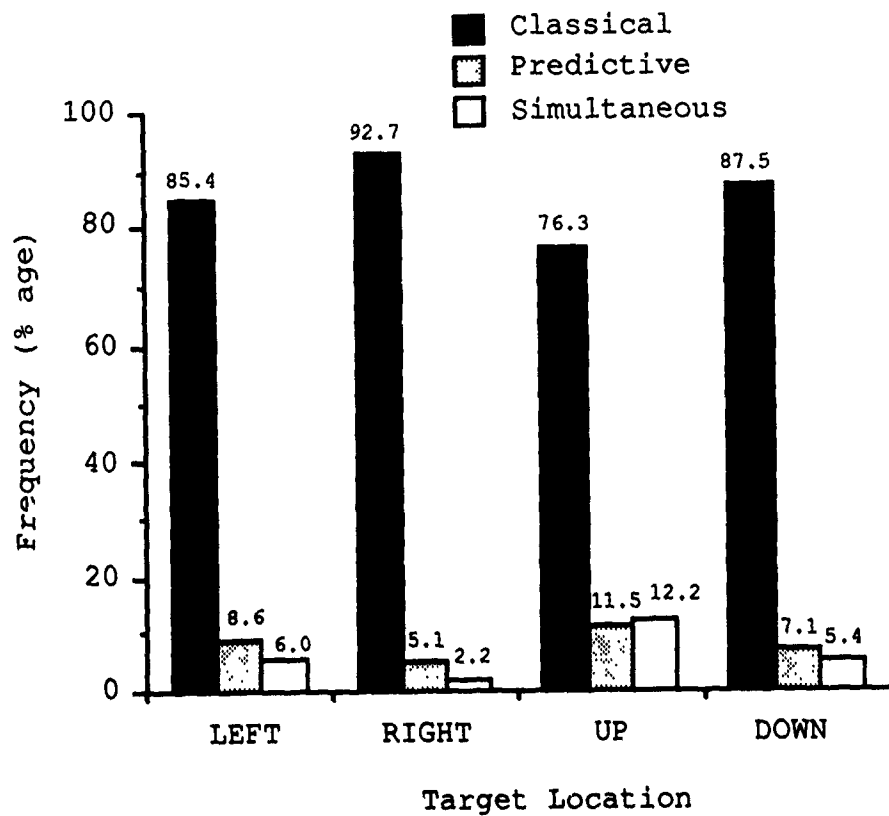
Figure 8. Response Pattern by Target Location
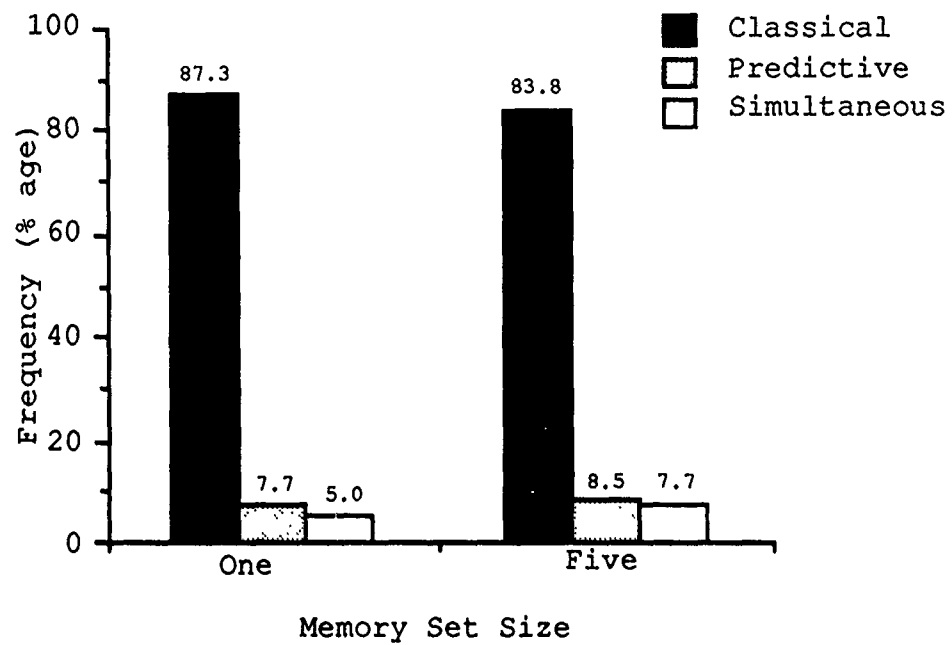
Figure 9. Response Pattern by Memory Set Size

Table 5

ANOVA for Classical Pattern

Source of Variance	SS	df	MS	Error Term	F	p
Memory Set Size (M)	448.096	1	448.096	Subject(M)	0.55	0.4804
Target Location (L)	2875.226	3	958.409	L*Subject(M)	1.93	0.1514
M by L	2438.590	3	812.863	L*Subject(M)	1.64	0.2069
Subject(M)	6545.531	8	818.191			
L*Subject(M)	11908.569	24	496.190			
Total	24216.012	39				

head by 75 ms; for the predictive pattern, head movement preceded eye movement by 114 ms . In the interest of further examining this relationship between eye and head, Pearson correlations were computed. The results indicated that the correlation between eye and head movement for the classical response was significant across target locations (Pearson r = .62, p < 0.0001). In fact, the correlations tend to increase with the target angle (Pearson r = .53, p < 0.0001 for 40 degree locations; Pearson r = .76, p < 0.0001 for 60 degree locations). Due to the small number of cases for the predictive and simultaneous patterns, no correlations were performed.

Manual Tracking Performance

The overall difference in RMS error between the two segments was 0.245 inches (see Table 6). In general, these differences were slightly larger for the right and upper target locations (0.277 and 0.255 inches, respectively) than for the left and lower target locations (0.235 and 0.213 inches, respectively). Similar variability was observed between the two memory set sizes (0.232 inches for memory set size one, and 0.258 inches for memory set size five). While the ANOVA detected no significant main effects for the RMS difference as a function of the target location and the memory set size, a significant effect was found for the interaction of the two variables (see Table 7). An analysis of simple effects was then performed for target location at each level of memory set size, resulting in a significant effect for target location for memory set size one, F (3,24) = 5.25, p < .05. This was followed by an analysis of simple comparisons among each target location for memory set size one (Keppel, 1982). The results specifically identified the origin of the interaction as between the right and lower target locations, with the RMS difference statistically larger for the right target location (0.310 inches) than for the lower target location (0.155 inches - see Figure 10).

Verbal Response Time

The mean overall verbal response time was 1369 ms, with average values ranging from 1328 to 1405 ms (see Table 6). The verbal response times were slightly longer for the left and right target locations (1390 and 1384 ms, respectively) than for the upper and lower target locations (1358 and 1344 ms, respectively). Similarly, there were only slight variations between the memory set sizes (1362 and 1376 ms, respectively, for memory set size one and five). The ANOVA detected no significant differences in the mean verbal response time as a function of target location, memory set size, or the interaction of target location with memory set size (see Table 8).

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Table 6

Manual Tracking and Verbal Response Time Performance

Memory Set Size

	One				Five				Overall Mean	
	Tracking (inches)		Verbal (ms)		Tracking (inches)		Verbal (ms)			
Target	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	Tracking	Verbal
Left	0.247	(0.103)	1381	(149)	0.222	(0.063)	1398	(144)	0.235	1390
Right	0.310	(0.123)	1405	(190)	0.244	(0.083)	1363	(137)	0.277	1384
Up	0.216	(0.057)	1333	(208)	0.294	(0.114)	1383	(87)	0.255	1358
Down	0.155	(0.095)	1328	(173)	0.272	(0.04)	1360	(141)	0.213	1344
Overall Mean	0.232		1362		.258		1376		.245	1369

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Table 7

ANOVA of RMS Error for the Manual Tracking Task

Source of Variance	SS	df	MS	Error Term	F	p
Memory Set Size (M)	0.0067	1	0.0067	Subject(M)	0.33	0.5813
Target Location (L)	0.0221	3	0.0074	L*Subject(M)	1.93	0.1513
M by L	0.0554	3	0.0185	L*Subject(M)	4.85	0.0089 *
Subject(M)	0.1632	8	0.0204			
L*Subject(M)	0.0914	24	0.0038			
Total	0.3388	39				

* Significant

Figure 10. RMS Difference for Memory Set Size One

Table 8

ANOVA for Verbal Response Time

Source of Variance	SS	df	MS	Error Term	F	p
Memory Set Size (M)	0.0020	1	0.0020	Subject(M)	0.02	0.8841
Target Location (L)	0.0138	3	0.0046	L*Subject(M)	1.41	0.2647
M by L	0.0118	3	0.0039	L*Subject(M)	1.20	0.3319
Subject(M)	0.7157	8	0.0895			
L*Subject(M)	0.0786	24	0.0033			
Total	0.8219	39				

DISCUSSION

Eye Latency

The eye latencies were very comparable across the four target locations. While such similarities had previously been shown between left and right target locations (Nelson et al., 1978), the present study provides additional data which suggest that such similarities also exist between upper and lower target locations, as well as between targets positioned along the horizontal and vertical peripheries. Even though this tends to contrast with previous efforts which have found significantly longer eye latencies to lower versus upper target locations (Heywood and Churcher, 1980; Hackman, 1940; Miles, 1936), those efforts differed from the present study in that they involved single task paradigms, smaller target displacements (less than 20 degrees, collectively), and a restrained head. The present study, on the other hand, suggests that, in the presence of competing central and peripheral tasks, when the head is free to move, latencies to larger target displacements (i.e., at least 40 degrees), regardless of periphery, are less distinguishable. However, the strength of such speculation rests on conducting additional studies which involve more target locations across a wider field-of-view.

The lack of significant differences among the target locations tends to suggest that the 20 degree disparity between the locations along the horizontal and vertical periphery had little impact on the eye latencies. While this provides further support for the notion that eye latency does not significantly increase with target angle, it must be kept in mind that the present study involved displacements of only 40 and 60 degrees.

In addition, the lack of significant differences as a function of the memory set size tend to suggest that the Sternberg task load, as varied in this study, had virtually no effect on the initiation of the saccade (i.e., the larger memory set size did not delay the eye or head latency in any appreciable degree above that observed for the smaller memory set size). While the original intent of employing the Sternberg task was to instill some degree of cognitive load in the peripheral task on the subject and determine if such loads were manifest in the eye and head latency, it may be that processing of the Sternberg task and initiation of eye (head) latency utilize separate resources which, according to multiple resource theory (Wickens, 1981), would result in efficient time-sharing between the two tasks, thereby minimizing any effect between memory set size and the latency response. One other possibility may be that the present study did not truly capture the impact of the cognitive load at a time sensitive to the initiation of the eye (or head) latency. It is possible that memory set size did not have

a significant impact on these latencies because recall of the positive target was not required until <u>after</u> the eye and head latencies were initiated. Thus, any differences in the mental processing of the peripheral target resulting from the memory set sizes most likely occurred following the eye and head latencies. Following this reasoning, one might expect longer verbal response times for the larger memory set size. An examination of these data among the memory set sizes supports this claim, although these differences are not statistically significant.

Perhaps a more effective approach to examining the potential effects of the Sternberg task on eye and head latency would be to manipulate memory set size as a within-subjects variable, and to elicit recall of the positive targets at cue time. For instance, in the context of the present study, the visual cue (i.e., bar) could be represented by a Sternberg probe. This probe would not only prompt a classification response (i.e., positive or negative), but would also indicate the target direction. The peripheral task could consist of another letter classification. This paradigm would provide a more accurate assessment of the effect of the cognitive load (i.e., Sternberg), with a time more closely associated with initiation of the latency response.

As for the actual latency values, the overall mean of 415 ms compares favorably with the 428 ms reported by Robinson and Rath (1976), while it is slightly less than the 502 ms reported by Robinson and Bond (1975), under similar conditions. It should be added that the latencies observed in this study are sufficiently longer than the values one would expect under single task conditions (i.e., 150-250 ms), lending support to Robinson's (1979) contention that "interrupting something" can have the quantitative effect of increasing the eye latency. While the latencies are not of the 700 ms magnitude proposed by Robinson for situations where the central task is considered primary, it may be that, in the present study, the subjects perceived the two tasks serially, whereby the subjects did not consider either task as primary, but rather as two distinct events conducted as efficiently as possible. It is also conceivable that the eye latencies reported herein reflect the immediacy of responding to peripheral stimuli which appear for only a short time, as well as task instructions which urge the subjects to do their best at all times with the possible consequence of receiving monetary rewards for their efforts. Additional investigations are needed in order to further isolate and clarify the relevant effects of competing stimuli on the latency response. Furthermore, the fact that the latency values for the eye (and head) are considerably higher than the 350 ms delay between cue and target presentation further assures that this delay did not affect the latency responses. Keep in mind that the latencies reflect initial onset times, and do not include eye and head excursion times to the targets.

Head Latency

The overall head latency of 477 ms is comparable to the 490 ms reported by Robinson and Bond (1975), and the 532 ms reported by Robinson and Rath (1976). Contrary to the eye latency, the mean head latency did show a significant effect for target location. The finding that the mean head latency was significantly longer for the lower target location

than for any of the other three target locations (including its 40 degree counterpart in the upper vertical periphery) suggests that the precise location of the target, rather than the target angle, was the more influential factor. That is, the mean head latencies were nearly identical for the 60 degree left and right, and 40 degree upper target locations (469, 463, and 464 ms, respectively), with the only other distinguishing characteristic being the target location.

Insofar as providing explanations for the longer head latencies to the lower target location, one possibility may be that the subjects adopted different response strategies for the locations along the vertical periphery. As mentioned previously, one subject never initiated head movement to the lower target, while two others exhibited downward head movement less than 50% of the time. Similarly, one subject never initiated head movement to the upper target location. In contrast, all the subjects displayed head movements for the left and right target locations. It is highly likely that such distinctions regarding the initiation of head movement between the target locations across the vertical and horizontal periphery result from differences in the angular displacements between these target locations. As Sanders' (1970) functional visual field concept would suggest, the perception of a 40 degree target location can fall within the realm of the eye field, where the target can be seen without head movement. In the present study, the subjects may have adopted a response strategy to the upper and especially the lower target locations which effectively minimized or potentially delayed the head movement response until the last possible moment when such movements were necessary to acquire the target.

The critical question then becomes one of addressing the greater variability in the head movement response for the lower target location. One possibility may be the helmet cables, where movements of the head along the vertical periphery may have resulted in shifts of the helmet's center of gravity, thereby affecting, and perhaps delaying, the head latency. Still, one other possibility may be linked to the preferred viewing angle. Prior to the start of each session, the subject was positioned such that the forward line-of-sight (or roughly the Frankfort plane) was parallel with the center of the tracking monitor. While it has been suggested that the preferred line-of-sight is approximately 15 degrees below this Frankfort plane (Huchingson, 1981), this means that the subjects performed the tracking task above that which would be prescribed under preferred viewing conditions. It may be that, when the subject responded to the lower target location, the inherent movement toward the direction of the preferred viewing area allowed the eyes to traverse a larger portion of the lower vertical periphery (before necessitating head movement) than was possible for refixations to the left, right, or upper target locations. Thus, one might anticipate a delay in the response of the head latency for the lower target. This concept would also account for the lack of significant differences in the mean eye latency across the target locations, for one would not expect the preferred viewing angle to affect the initiation of the eye latency response, but, rather, the amplitude of the response. It would be of interest to place the tracking monitor at the preferred viewing angle and then reexamine the characteristics of the eye and head (including amplitude differences) to further attest to the prevalence of such response tendencies.

Eye and Head Response Patterns

The finding that the classical pattern was observed in 85.5% of the trials is directly comparable to the 83.3 and 81% found by Calhoun (1987) and Nelson et al. (1978), respectively. While contrary to other dual task studies which have found a greater tendency for the predictive pattern (Mourant and Grimson, 1977; Robinson and Bond, 1975; and Robinson and Subelman, 1975), the specific factors underlying the selection of a particular response remain unclear. Mourant and Grimson suggest that the predictive pattern is most likely in situations where the central task demands continuous monitoring. That is, one might expect the percent of predictive patterns to increase with the difficulty level of the central task. This appears to be a valid argument when one considers that the studies that have found a preponderance for the predictive pattern have typically utilized complex central tasks. For instance, the studies of Mourant and Grimson, and Robinson and Subelman used actual and simulated driving conditions, respectively; while Robinson and Bond instantaneously varied the complexity of the central task. In contrast, the present study utilized one level of tracking task difficulty, which, although challenging, may not have approached the level of complexity needed to elicit more predictive responses.

It is possible that at least two additional factors may have also contributed to the subject's tendency to elicit the classical response. First, the subjects were reinforced for making efficient responses. Thus, it is likely that the subjects initiated eye movement first in order to acquire the peripheral target as quickly as possible, thereby minimizing time away from the central task and enhancing performance. Second, the predominance of the classical response may have resulted, in part, from the four-second interval in the presentation of the peripheral task, thereby instilling a certain level of urgency on the subjects to respond as quickly as possible before the target was extinguished. Thus, one would expect the subject to initiate the faster eye before the slower head, thereby resulting in classical responses. It would be informative to further explore these possibilities by performing studies where the complexities of the cental task are manipulated, as well as the priorities assigned to the central and peripheral tasks.

Although the overall correlation of .62 for the classical response across the target locations is considerably lower than the .98 reported by Robinson and Bond (1975), it may be that correlations of such magnitude are directly related to the target angle. For instance, Robinson and Bond's estimate is based on 90 degree target displacements, whereas, for the present study the estimate is based on the correlation across the target locations without regard for the target angle. If the correlations are examined by target angle, the coefficients become .53 and .76 for the 40 and 60 degree target locations, respectively. These, taken together with Robinson and Bond's estimate, suggest an apparent increase in the correlation of the classical response as the target angle increases. Considering that the degree of eye and head movement initiated towards peripheral targets increases with target angle, perhaps such tendencies should be expected.

The 75 ms lag between the initiation of head movement following eye movement in the classical response is slightly longer than the 50 ms delay observed by Bizzi (1974) and Robinson (1979), but is quite comparable to the 68 ms delay reported by Nelson et al.

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(1978). The 114 ms lag between the initiation of eye movement following head movement in the predictive response is well within the estimated range of 100 to 200 ms noted by Robinson (1979).

Manual Tracking Performance

As the effect of interrupting the manual tracking task resulted in an overall degradation of .245 inches, it appears that the subjects, as a group, were very efficient in shifting between the central and peripheral tasks. Of particular mention is the significant interaction found between memory set size and target location. The results indicated that, for the smaller memory set size, the degree of degradation was significantly greater when responding to the right target location than the lower target location. However, the difference in degradation between these two target locations is only .155 inches; which amounts to negligible practical significance.

Verbal Response Time

Although this specific experiment was not concerned with verbal response time, the verbal response data were useful in identifying incorrect verbal responses. It is of interest to note, however, that similar to the eye latency data, the verbal response time did not differ statistically as a function of memory set size or target location.

CONCLUSIONS

The present study was unique in that it examined both the eye and head latency for refixations along the horizontal and the relatively unexplored vertical periphery. The eye latencies did not differ across target locations, and exhibited values similar to those previously reported for refixations along the horizontal periphery (Robinson and Rath, 1976). Likewise, while the head latency values were also comparable with previous data (Robinson and Bond, 1975; Robinson and Rath, 1976), significantly longer latencies were found for the lower vertical periphery. Additional data are needed to further clarify if such effects in the head latency actually represent differences resulting from the target angle (40 degrees) or are the product of the target direction. Similarly, the variability in the head movement response observed between the 40 and 60 degree target displacements suggests that Sanders' notion of a functional visual field may also have ramifications for the vertical periphery. Additional studies involving the vertical periphery are needed to further clarify such eye and head response tendencies.

The classical pattern was, by far, the dominant response exhibited by the subjects regardless of target location. While others have observed similar tendencies (Calhoun, 1987; Nelson et al., 1978), some have found the predictive pattern more likely (Mourant and Grimson, 1977; Robinson and Bond, 1975; and Robinson and Subelman, 1975). While a host of factors may account for such discrepancies, the level of complexity of the central

task, the experimental setting, and the task instructions may be the most likely contributors. Although the memory set size yielded no significant differences between the eye and head response, it would be of interest to study further the effects of the Sternberg task, but, most notably, at a time more closely associated with the initiation of the latency response. In this way, further clarification would be provided on the effects, if any, of processing load on the eye and head latency.

Finally, it should be mentioned that comparisons of these data with those of previous studies must be interpreted with caution. Since the criteria used to determine the eye and head latency are rarely reported in the literature, precise replications of studies are difficult, if not impossible, and generalizations across studies are severely limited. However, the present data do provide useful estimates of the eye and head latency, which, in conjuction with previous efforts, are beneficial in establishing general trends for the latency response. Additionally, such data are very useful for the further development of oculomotor models applicable to the design, simulation, and use of complex person-machine technology such as that proposed by AAMRL involving visually-coupled systems.

APPENDIX A

Due to very limited documentation, the development of criteria for detecting the initial onset of the eye and head response proved to be a challenging task. Countless approaches were undertaken and evaluated prior to selecting the single criterion which appeared to most accurately and reliably detect the latency response. Originally, these criteria were based on comparing the net eye and head movement for each sample with that at cue time, and identifying the latency whenever such movement differed by at least 1.5 degrees across three consecutive samples (50 ms). However, after selecting some of these estimates and plotting the respective eye and head time history data, it became apparent that further iterations were needed. These iterations included varying the critical level for the net eye movement (e.g., changing 1.5 to 2.0 degrees), modifying the number of consecutive data samples needed at this level (e.g., changing 3 samples to 5 samples), and examining velocity levels between consecutive samples. The purpose of this appendix is to describe, step-by-step, the methodology derived from these efforts in determining the response latencies in this study.

In determining the eye and head latency, a velocity criterion was established whereby the velocity of successive eye and head samples was compared, respectively, in order to detect abrupt changes suggesting the initiation of a saccade or head movement. Table A.1 shows a representative sample of eye azimuth and elevation data, as well as additional variables generated in the process of detecting the latency response. This table will be useful in clarifying the steps described below:

Step 1 - Assuming that the visual cue was just presented, the difference was first calculated for each eye azimuth (IAZ) and eye elevation (IEL) value from its respective value at the time the visual cue was presented (i.e., CUETIME). Referring to Table A.1 this difference resulted in DIFIAZ/DIFIEL, respectively. For example, the DIFIAZ value for sample 25 was calculated by subtracting the IAZ value for this sample (i.e., -0.237), from the IAZ value at cue time (i.e., 1.694), yielding -1.931.

Step 2 - These values were then redefined in absolute terms in order to determine the absolute magnitude of the eye movement from its initial position at cue time. These values became ABSAZ and ABSEL, respectively. Thus, each DIFIAZ and DIFIEL value became an absolute value (e.g., -1.931 became 1.931).

Step 3 - The net eye movement (in degrees) was then calculated for each eye sample

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Table A.1
Sample Data

Sample*	Time	IAZ	IEL	DIFIAZ	DIFIEL	ABSAZ	ABSEL	IDIS	IDIFF	COUNTER
1	73.520	1.694	-8.926	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	...
24	...	...	...	...	...	...	...	...	...	...
25	73.928	-0.237	- 7.798	-1.931	1.128	1.931	1.128	2.236	0.047	0
26	73.934	-0.413	- 7.835	-2.107	1.091	2.107	1.091	2.370	0.134	0
27	73.951	-0.536	- 7.763	-2.230	1.163	2.230	1.163	2.520	0.142	0
28	73.968	-0.654	- 8.178	-2.348	0.748	2.348	0.748	2.460	0.051	0
29	73.986	-0.671	- 8.245	-2.365	0.681	2.365	0.681	2.460	0.003	0
30	74.003	5.326	- 8.116	3.632	0.810	3.632	0.810	3.720	1.260	1
31	74.02	7.954	-13.861	6.260	-4.935	6.260	4.935	7.970	4.250	2
32	74.035	-7.728	2.207	-9.422	11.133	9.422	11.133	14.580	6.614	3

* Sample 1 begins at cuetime

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from cue time, utilizing the following formula:

$$IDIS = \sqrt{(IAZ - CUETIME\_IAZ)^2 + (IEL - CUETIME\_IEL)^2}$$

Referring once again to sample 25:

$$IDIS = \sqrt{(-0.237 - 1.694)^2 + (-7.798 - (-8.926))^2} = 2.236$$

Step 4 - The absolute difference was then subtracted between two successive IDIS calculations, beginning with sample 2 minus sample 1, sample 4 minus sample 3, and so on. This resulted in the variable IDIFF. As an example, the IDIFF value of 0.134 for sample 26 was derived by subtracting the absolute difference between IDIS values 2.370 (sample 26) and 2.236 (sample 25). The IDIFF value represented the degree of eye movement between 2 successive samples. IDIFF also provided a means for determining the change in eye velocity from one sample to the next. As the oculometer used in this study operated at 60 Hz, a typical eye position sample was collected every 16.67 ms. Thus, an IDIFF value of 1 degree represented a shift in eye velocity of 60 deg/sec from the previous sample (1/.016667 = 60 degrees). However, on some occasions, the actual shift in velocity could be less than or greater than 60 deg/sec, even though IDIFF equaled 1 degree. This was due to artifacts in the data (such as eye blinks, which the system ignored), which consequently increased or decreased the sample time between successive eye samples.

Step 5 - The eye movement velocity between 2 successive eye samples was then examined to determine if the velocity met the level established for identifying a saccadic event. In this study, a velocity of 60 deg/sec was selected as the minimum velocity for detecting the onset of an eye movement. Therefore, the IDIFF value had to be at least 1, and in cases where this was true, a counter was started. This velocity level was chosen for a number of reasons. Primarily, a conservative value was desired which would readily indicate a saccadic event. In this manner, the probability of detecting a false eye movement (Type I error) was reduced. In determining an appropriate level, the average gaze velocity was calculated for a subject when completing the central tracking task. This velocity was found to be 12 deg/sec. This estimate provided an understanding of the average velocity of the summed eye and head movements when the subject was strictly performing the central task. In this way, a legitimate velocity could be estimated for the eye and head when such movements were directed away from the central task. While this calculation was based on one subject, it was assumed to represent all the subjects, since the structure of the tracking task was the same across all participants. Since 60 deg/sec is considerably greater than 12 deg/sec, it was felt that a conservative velocity level had been achieved for detecting a saccadic event. This contention was further supported by velocity estimates as low as 20 and 30 deg/sec previously used for detecting similar saccadic events (respectively, Bahill, Brockenbrough, and Troost; 1981, and Van Gisbergen, Smit, and Berg, 1988). Furthermore, in-house analyses of time history plots for the eye data supported the selection of 60 deg/sec in detecting accurate latencies.

Step 6 - Once three consecutive IDIFF values of 1 were detected, the eye latency was

calculated. The eye latency time was determined by back tracking to the last sample where IDIFF was less than 1 (sample 29 in Table A.1), and subtracting this sample time from the cue time. This value then represented the time at which the eye began its initial movement towards the target. Thus, for the trial represented in the table, the eye latency would be 466 ms (i.e. 73.986 (time of sample 29) minus 73.520 (cue time) = 466 ms).

In determining the head latency, an identical procedure was used, except that the velocity criterion for the head was based on shifts of 15 deg/sec across 3 consecutive head distance values. The reduced velocity for the head was used to reflect the inherent differences in the velocities between the eye and head. Based on previous studies (Morasso, Bizzi, and Dichgans, 1973; Biguer, Jeannerud, and Prablanc, 1982), as well as in-house analyses of time history plots of head data, a criterion of 15 deg/sec appeared to provide very accurate detection of head latencies.

Direction of eye movement was determined by a two-step process: first, by defining the periphery in which the movement occurred (i.e., summing the ABSAZ and ABSEL values across the three samples, which determined the latency, and then selecting the largest value); and second, by examining the respective IAZ or IEL values (across the same three samples) to determine the actual movement direction from the selected periphery. For example, if ABSAZ (azimuth) had the larger value, then the IAZ values were examined to determine if the majority of moves were left or right. An identical procedure was also used for establishing the head movement direction.

APPENDIX B

Note: While the following subject instructions represent those given in the context of the entire study, (i.e., all 5 cue conditions), only those effects resulting from the visual cue condition were addressed in this study.

Session 1

Introduction

Thank-you for serving as a subject in the Helmet Mounted Oculometer Facility. The purpose of this experiment is to examine your performance on two tasks with five different types of attention cues. One task will involve symbols displayed on the central monitor, while the other task will involve letters displayed on the other four monitors. Each of the five types of cues will give you information as to which of these four peripheral monitors will present a letter target. Evaluation of your performance on the central and peripheral tasks, as well as your eye and head movement data and your responses to a debriefing questionnaire, will help indicate which of these cue conditions may be beneficial in future fighter cockpits.

Precautions

When you climb into the cockpit, we ask that you avoid stepping on the switch on the left console. After we adjust the position of the seat, we'll fit you with the helmet. There are several things we would like to remind you about the care of the helmet and visor:

1. First of all, please don't touch the visor. The visor must be kept very clean; and as a precautionary measure we would like you to wear cotton gloves throughout the entire session. You should still exercise extreme caution in avoiding contact with the visor, but in the event you do, the gloves serve as an aid in reducing the amount of skin oil that gets on the visor.

2. Once we place the helmet on your head with the necessary helmet pads inserted, we will fasten the chin-strap and adjust it so it fits snugly under your chin.

3. *After* the chin-strap is fastened, we will ask you to inflate the ear bladders until the helmet feels snug on your head. Remember, fasten the chin-strap before inflating the ear bladders.

4. We will raise and lower the helmet visor for you, and attach the helmet cables to the back of your seat for greater comfort. Let us know if the visor springs up – the clip doesn't always hold.

5. Let us know if the helmet gets uncomfortable or slips on your head so that we can move and reposition the helmet for you.

6. Remember, be very careful not to bump the visor against any surface, or touch the visor, especially the reflective patch in front of your right eye.

7. If an emergency should occur and you need to get out of the helmet without assistance, perform the following steps in order:

    (a) Raise the visor by pulling outward on the visor clip located on the upper left side of the helmet.

    (b) Let the air out of the ear bladder by turning the valve near the bulb.

    (c) Unfasten the chin-strap.

    (d) Release the helmet cables on the upper right of the seat by pulling the velcro strap.

    (e) Carefully take off the helmet and place it on the seat without bumping the visor.

    (f) Exit through one of the two doors in the lab.

8. There is a light pen on the canopy in the event of a power outage.

9. We also ask that you always sit in approximately the same position in the cockpit for the entire session.

Tasks

   The experimental runs will involve two simultaneous tasks: a central task and a peripheral task. To encourage you to give equal consideration to both of these tasks, we are using a financial incentive system which you've already been briefed on. Remember, your performance on *both* the central and peripheral tasks will be recorded and analyzed.

Centrally located task

   This manual pursuit tracking task will involve symbology displayed on the central monitor straight in front of you. The symbology for the tracking task will be a dot and a cross-hair. By applying force on the joystick, your task will be to put the dot on top of the continually moving cross-hair. Your performance will be measured in terms of the average

distance of the dot from the cross-hair during a run.

Peripherally located task

The peripheral task will involve letters which will periodically appear on the four monitors surrounding the tracking monitor. For each trial, one letter will be presented on each of the four peripheral monitors. Your task is to direct your attention to the monitor indicated by the visual or aural cue and determine, within four seconds, whether the letter is a member of a positive set you were given to memorize.

Memory set size one:

If the target presented is the letter "Q", you are to say the word "ALPHA"/"BRAVO" (*the subject was assigned one of these words*) into the microphone; if it is not the letter "Q", you are to say "ALPHA"/"BRAVO". Try to maintain a normal tone of voice when responding; otherwise the voice recognition system will have a difficult time recognizing your response. Both the speed and accuracy of your response will be recorded. The letter will disappear when you make a response. If, for some reason, you do not make a response, the letter will disappear in about 4 seconds. This type of error will also be recorded.

Memory set size five:

If the target presented is one of these five letters – "A", " H", "Q", "U", or "Z", you are to say the word "ALPHA"/"BRAVO" into the microphone; if it is not one of these five letters, then say "ALPHA"/"BRAVO". Try to maintain a normal tone of voice when responding; otherwise the voice recognition system will have a difficult time recognizing your response. Both the speed and accuracy of your response will be recorded. The letter will disappear when you make a response. If, for some reason, you do not make a response, the letter will disappear in about 4 seconds. This type of error will also be recorded.

Attention cues

Shortly before the letters are presented you will receive some type of cue. Each of the five types of cues will give you information as to which one of the four peripheral monitors you are to look at in order to make your response. Remember, speed is important, so attend to the appropriate monitor as soon as you can. You *do not* have to wait until the entire cue has sounded. We will now describe each of these directional cues in order to familiarize you with them. Don't worry about remembering them all; we will review the cue condition you are to have at the beginning of each session.

Visual cue: A visual bar will appear either on the left, right, top or bottom of the tracking monitor screen to indicate the direction of the target monitor. In other words, if the bar appears on the top of the tracking monitor, it means that the target letter will appear on the upper monitor.

Coded tone: You will hear four different tone bursts over the headset. Each is coded to indicate one of the four target monitors. Before running the sessions with this condition, we will have you listen and learn the directions represented by each tone.

Central speech cue: You will hear either the word "LEFT", "RIGHT", "UP", or "DOWN" to tell you the direction of the target monitor.

Peripheral tone: You will hear a single tone burst but it will appear to emanate or sound from the monitor which will present the target letter. Once you hear this three dimensional (3-D) tone, you will understand how it will cue you as to the direction of the target monitor.

Peripheral speech: You will have the same words: "LEFT", "RIGHT", "UP", and "DOWN" used in the previous speech cue condition, but in this case they will appear to emanate from the peripheral target monitor.

Remember, performance on *both* the central and peripheral tasks will be recorded. While you are completing the centrally located tracking task, the peripheral letters will be presented. Once you complete the letter task, you are to *immediately* resume the centrally-located tracking task. After the last target letter is presented, there will be a short time interval in which your only task will involve the central monitor. Continue tracking until the dot disappears from the central monitor.

Calibration procedure

Now we'll have you get in the cockpit, fit you with the helmet and describe the calibration procedure. This procedure "tunes" the system to the particular characteristics of your eye and the position of the helmet on your head.

1. First, the experimenter will stabilize the helmet with the helmet restraint system. Let us know if this configuration becomes uncomfortable.

2. To begin the calibration procedure, the experimenter will ask you to look forward to examine the accuracy of the system in tracking your eye. Next, you will be instructed to look at different lights. Tell the experimenter when you have a good steady fixation on the commanded light. Once you say "READY", it is very important that you maintain a steady fixation on this light until the experimenter turns the light off. Between lights you may momentarily rest your eyes before continuing.

3. If you feel that you have a "bad calibration" on any of the lights (e.g., you sneezed during the fixation), please let us know.

Unless you have any questions, we'll bring up the system.

Start up

1. First, we'll close the curtain and have you sit in the dark for about 5 minutes to allow your eyes to dark-adapt. You may use this time to relax, but please don't press any switches.

2. We will be in communication through the intercom during the entire session. Feel free to ask questions, especially between runs.

3. After the dark adaptation period, we'll turn on the light source and you'll see the red filament image reflect off the visor. While it starts to track your eye position, we'll start the experimental control program. When the computer starts beeping it's ready to collect data. We may have to reposition your helmet to get a better image of your eye. We will inform you when we are going to turn the light source on or off and when we are going to come into the curtained area to adjust your helmet or the restraint system. We will also tell you when to begin the calibration procedure and the steps to perform. After the calibration procedure is performed, we will remove the helmet restraint device and tell you when to start the first run.

4. Before we start, are there any questions?

5. Prior to each session, we will review the tasks and cue condition you will have. Each session will consist of 8 runs, each lasting about five minutes. If you need a few minutes break in the cockpit, let us know. It will take approximately 14 more sessions like this to collect the data that we need. We will probably run three sessions each week, one week for each of the five cue conditions.

Subsequent sessions

First, we want to review a few things to remember about the helmet and the visor:

1. Don't touch the visor or allow it to touch any other surface. We will raise and lower it for you.

2. Always inflate and deflate the ear bladders with the chin-strap fastened.

3. Let us know if the helmet or restraint system gets uncomfortable and we will adjust it for you.

Second, let's review the tasks you will perform and the cue condition to be presented. You have been assigned the positive memory set size ___ for your peripheral letter task. Thus if either ("Q")/("A", "H", "Q", "U", or "Z") is presented respond into the microphone: "ALPHA"/"BRAVO". If the letter is not a member of your memorized set, respond "ALPHA"/"BRAVO". You will have one of five different types of cues: (visual bar on tracking display, coded tone, speech cue, localized 3-D tone, or localized 3-D speech cue). While you are completing the peripheral letter task you will also have a central tracking task. Remember, performance on both tasks will be recorded.

Questions?

APPENDIX C

Subject Consent Forms

I, _____, am participating because I want to. The decision to participate in this research study is completely voluntary on my part. No one has coerced or intimidated me into participating in this program.

_____ has adequately answered any and all questions I have asked about this study, my participation, and the procedures involved, which are set forth in the addendum to this Agreement, which I have initialed. I understand that the Principal Investigator or a designee will be available to answer any questions concerning procedures throughout this study. I understand that if significant new findings develop during the course of this research which may relate to my decision to continue participation, I will be informed. I further understand that I may withdraw this consent at any time and discontinue further participation in this study without prejudice to my entitlements. I also understand that the Medical Consultant for this study may terminate my participation in this study if he/she feels this to be in my best interest. I may be required to undergo certain further examinations, if in the opinion of the Medical Consultant, such examinations are necessary for my health and well being.

I understand that my entitlement to medical care or compensation in the event of injury are governed by federal laws and regulations, and that if I desire further information I may contact the Principal Investigator.

I understand that for my participation in this project I shall be entitled to payment as specified in the DOD Pay and Entitlements Manual or in current contracts.

I understand that my participation in this study may be photographed, filmed or audio/videotaped. I consent to the use of these media for training purposes and understand that any release of records of my participation in this study may only be disclosed according to federal law, including the Federal Privacy Act, 5 U.S.C. 552a, and its implementing regulations. This means personal information will not be released to an unauthorized source without my permission.

I FULLY UNDERSTAND THAT I AM MAKING A DECISION WHETHER OR NOT TO PARTICIPATE. MY SIGNATURE INDICATES THAT I HAVE DECIDED TO PARTICIPATE HAVING READ THE INFORMATION PROVIDED ABOVE.

VOLUNTEER SIGNATURE AND SSAN	DATE

WITNESS SIGNATURE	DATE

ADDENDUM TO THE CONSENT FORM

Eye-Position Mediated Cockpit Controls

You are invited to participate in an experiment entitled "Eye-Position Mediated Cockpit Controls". In each study we will evaluate the movements of your eye and head while you look at different symbols/switches on the cockpit controls/displays. You may also be required to: a) perform tracking tasks or select symbols/switches with either eye, head, hand, or voice control and, b) listen and respond to multimodality attention cues.

You must wear a specially designed helmet to permit eye position to be determined (cotton gloves must also be worn as a precautionary measure against visor damage). On the helmet are mounted (1) a dim source of infrared light and (2) a lightweight television camera. The reflection of the infrared light from the eye is monitored by a computer through the television camera. The amount of light used is less than that which would enter the eye while outside on a sunny day. This exposure amounts to less than one-half of the national safety standard. No physical, psychological, or social risks are expected by your involvement in this study.

Your confidentiality as a participant in this program will be protected. Your identity will only be revealed in accordance with the Privacy Act, 5 U.S.C. 552a and its implementing regulations. Statistical data collected during the test program may be published in scientific literature without identifying any individual.

Monetary benefits will be according to Air Force and Systems Research Laboratories, Inc. agreements.

No alternative means exist to obtain the required information. Your decision to participate will not prejudice your future relations with the Harry G. Armstrong Aerospace Medical Research Laboratory. If you decide to participate, you are free to withdraw your consent and to discontinue participation at any time without prejudice. If you have additional questions later, Ms. Gloria Calhoun (255-7595) will be happy to answer them.

AT YOUR REQUEST, YOU WILL BE GIVEN A COPY OF THIS FORM TO KEEP.

_____   _____
DATE   Volunteer's Initials

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